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PHASE II STUDIES: IMPACTS OF COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS AT THE W. H. ZIMMER STATION, 1989-90 BASELINE STUDIES

by

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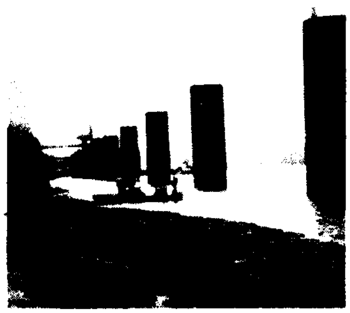

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13. ABSTRACT *(Maximum 200 words)*

Qualitative and quantitative baseline data were obtained at nine and six sites, respectively, at a mussel bed located on the Ohio River (river mile (RM) 444.4 to RM 445.6) near the W. H. Zimmer Station, in July 1989 and September 1990. This information, in conjunction with data to be collected after the power plant has operated for at least 1 year, will be used to assess the effects of coal deliveries by barge on freshwater mussels (Family: Unionidae). Total species richness (24) was similar to that at other large-river mussel beds. Average unionid density ($\pm$SD) at RM 444.4 and RM 444.6 (36.7 ± 20.4 and 45.9 ± 14.8 individuals/m^2, respectively) was slightly less than typical values at similar habitats. The unionid fauna consisted almost entirely of thick-shelled species and was dominated by *Pleurobema cordatum* (20.3 percent), *Quadrula metanevra* (18.7 percent), and *Quadrula pustulosa* (15.6 percent). The assemblage was characterized by an equitable distribution of species with no clear dominants. *Corbicula fluminea* ($1{,}227.7\pm274.2$ and 915.2 ± 155.5 individuals/sq m at RM 444.4 and 444.6, respectively) outnumbered unionids, although there was no evidence of

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competition (either in terms of density or biomass) between native and nonnative bivalves. Populations of dominant unionids consisted of large numbers of intermediate-sized individuals and moderate to low numbers of juveniles and adults. All had multiple age classes and showed evidence of moderately strong recruitment by several recent year classes.

Contents

Preface

The Mussel Mitigation Trust funded the US Army Engineer Waterways Experiment Station (WES) under Contract No. 105 to collect baseline data on freshwater mussels at the W. H. Zimmer Station on the Ohio River near Cincinnati, OH. The purpose was to obtain information to evaluate impacts of increased barge traffic at the plant, which is owned by The Cincinnati Gas & Electric Company, Columbus Southern Power Company, and Dayton Power and Light Company. This report describes baseline data collected in 1989 and 1990.

This report was prepared by Drs. Andrew C. Miller and Barry S. Payne of the Aquatic Habitat Group (AHG) at WES. Technical assistance was provided by Mr. Scott Schermerhorn, Ms. Cheryl Tansky, and Dr. Albert Burky, all with the University of Dayton, and Ms. Sarah Wilkerson, WES.

Dr. Edwin Theriot was Chief, AHG, Dr. Conrad J. Kirby was Chief, Environmental Resources Division, and Dr. John Harrison was Chief, Environmental Laboratory, WES, during the conduct of this study. Mr. Alan Gaulke, AEP, monitored the contract and reviewed an early draft of this report. Additional review comments were provided by representatives from the US Fish and Wildlife Service, the Kentucky Department of Fish and Wildlife Resources, and the Ohio Department of Natural Resources. The report was edited by Ms. Janean C. Shirley of the WES Information Technology Laboratory.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers

1 Introduction

Background

Project history

Conversion of the W. H. Zimmer Station, located on the Ohio River near Cincinnati, OH, from nuclear to coal power required construction of a harbor and a barge-loading facility for coal, lime, and fuel oil. The plant began operation in 1990, and coal deliveries by barge started that year. The loading facility is near a dense and diverse bed of freshwater mussels (Williams 1969, Williams and Schuster 1982, Stansbery and Cooney 1985). As a condition of the permit required by the US Army Engineer District, Louisville, approximately 5,000 mussels were taken from a section of the bed that had to be dredged and moved upriver (Environmental Science and Engineering, Inc. 1988). In addition, plant owners were required to establish a trust to fund research on unionid molluscs. The trust is being administered by a committee composed of a representative of the Commissioner of the Kentucky Department of Fish and Wildlife Resources, the Director of the Ohio Department of Natural Resources, and the owners of the Zimmer Station. The committee required that a study be conducted to determine if barge deliveries would negatively affect mussels near the plant. This will fulfill conditions of the US Army Corps of Engineers permit for the conversion.

In October 1988, the US Army Engineer Waterways Experiment Station (WES) received funds from the Mussel Mitigation Trust to conduct a literature review on biological effects of commercial navigation traffic (Miller, Payne, and Way 1989). The WES also prepared a scope of work describing a plan to monitor the effects of commercial traffic on freshwater mussels. Following completion of Phase I, WES prepared a proposal to conduct baseline studies at the Zimmer site. That proposal was subsequently funded, and WES initiated Phase II. Baseline data (collected in July 1989 and September 1990) will be used, in conjunction with results of studies to be conducted after the plant is operational (Phase III), to determine the effects of barge deliveries on freshwater mussels near the plant.

Historical information on bivalves

Rafinesque conducted a comprehensive survey of the Ohio River in 1820, and Shaffer studied the reach near Cincinnati in 1820 (as reported by Stansbery and Cooney 1985). Rhoads (1899) reported on mussels collected in the Ohio River below Pittsburgh. More recently, Taylor (1980) and Tolin, Schmitt, and Zato (1987) collected mussels in the Ohio River upriver of Pittsburgh using a brail and shoreline searches by hand. Neff, Pearson, and Holdren (1981) collected mussels in the lower Ohio River as part of an investigation of aquatic and riparian communities for the US Army Engineer District, Louisville. Studies on *Corbicula fluminea* in the Ohio River were conducted by Keup et al. (1964) and Bickel (1966).

Williams (1969) identified 23 species of mussels at the bed immediately downriver of the Zimmer site. In surveys conducted at this site by Dames and Moore Company (1980) and Williams and Schuster (1982), 16 species were identified. All of these investigators relied principally on the brail. Stansbery and Cooney (1985) collected 24 species of unionids using the brail and qualitative and semiquantitative techniques. In 1987, divers collected 23 species at this site as part of a mussel relocation experiment (Environmental Science and Engineering, Inc. 1988).

Purpose

The purpose of this study was to obtain baseline data on physical (water velocity and suspended solids) and biological conditions (density, species richness, relative species abundance, population demography of dominant species, etc.) at a mussel bed near the W. H. Zimmer Station on the Ohio River near Cincinnati, OH.

2 Study Area and Methods

Study Area

Location of the study area

The study area is located immediately downriver of the W. H. Zimmer Station on the right descending bank (RDB) of the Ohio River (Figure 1). The plant is about 0.5 mile[1] north of Moscow, OH, Clermont County, and 30 miles southeast (upriver) of Cincinnati. The study was conducted between river mile (RM) 444.2 and RM 445.6 at a mussel bed between Markland Lock and Dam (L&D) at RM 531.5 and Meldahl L&D at RM 436.0.

Baseline (Phase II) studies were conducted on 21-24 July 1989 and 17-20 September 1990. Data on stage height at 12 m. (noon) at Markland L&D (upper gage) and Meldahl L&D (lower gage) and on mean daily discharge at Markland L&D during these studies are summarized below.

	Markland L&D		Meldahl L&D
Date	Gage Height, ft	Discharge, cfs	Gage Height, ft
21 July 1989	12.3	67,300	15.3
22 July 1989	12.4	77,971	17.7
23 July 1989	12.3	88,539	15.6
24 July 1989	12.3	57,000	13.8
17 Sept 1990	12.3	72,500	18.0
18 Sept 1990	12.0	73,100	18.0
			Continued

1 A table of factors for converting non-SI units of measurement to SI units is presented on page vii.

Date	Markland L&D		Meldahl L&D
	Gage Height, ft	Discharge, cfs	Gage Height, ft
19 Sept 1990	12.3	74,800	17.4
20 Sept 1990	12.1	71,500	16.9

For the period of record (1970-1990) the average minimum and average maximum discharges at Markland L&D were 10,200 and 437,000 cfs, respectively. During the two study periods, 21-24 July 1989 and 17-20 September 1990, water level and stage height can be considered low, but not near recorded minima.

Location of specific study sites

Qualitative collections of mussels were obtained at nine sites (Table 1, Figure 1). In addition, mussels were collected using quantitative methods at RM 444.4 and 444.6 (1989) and 444.2 (1990). The site at RM 444.4 was located close to the loading facility and allowed for a 500-ft clear zone at a private boat club. The site at RM 444.6 was considered to be a reference site located outside the influence of either the boat club or the Zimmer Station. The site at RM 444.2 was chosen to be as close as possible to the last mooring cell on a downriver approach to the plant. Conditions at this site differed from those at RM 444.4 and 444.6. Divers reported evidence of recent dredging and substrate disturbance that were likely brought about by construction of the mooring cells. Based on analysis of substrate samples and qualitative observations made by divers, bedrock and coarse-grained material became more dominant moving away from the plant (i.e., downriver of RM 444.9). Therefore, sites chosen for intensive study were located close to the plant.

In 1989, water velocity and suspended sediment data were collected at nearshore and farshore stations at RM 444.4 (150 and 300 ft from the RDB, respectively). In 1990, water velocity data were collected 100 ft from the RDB (Table 1).

Methods

Qualitative mussel collections

Bivalves were collected by a dive crew equipped with surface air supply and communication equipment. Quantitative samples were obtained at each of the nine sites (Figure 1, Table 1) by three individuals who collected simultaneously. Each diver placed a specific number of live mussels in each of four nylon bags; five mussels were placed in the first bag, and twenty mussels were placed in each of the other three bags. All mussels

were brought to the surface by the divers, counted, and identified. Data were recorded in a field notebook and returned to WES for analysis and plotting. Shells of voucher specimens for each species were placed in plastic zipper-lock bags and labeled with high-rag-content paper. Mussels not needed for vouchers were returned to the river unharmed. Methods for sampling mussels are based on techniques described in Coker (1919), Brice and Lewis (1979), Miller and Nelson (1983), and Miller and Payne (1988). Mussel identification was based on taxonomic keys and pictures in Murray and Leonard (1962), Parmalee (1967), Starrett (1971), and Burch (1975).

While collecting qualitatively, divers attempted to exclude the Asiatic clam, *Corbicula fluminea*, from their samples. If *C. fluminea* was inadvertently collected, it was later eliminated. The purpose of qualitative collecting was to obtain a representative number of all native species present. The advantage is that large numbers of individuals can be quickly processed. At these nine locations, 1,798 mussels were collected and identified. Small individuals of certain species (i.e., *Truncilla donaciformis*) that were either missed or under-represented in the qualitative sampling were obtained using quantitative methods.

Quantitative mussel collections

Quantitative samples (that included unionids as well as *C. fluminea*) were obtained at RM 444.4, RM 444.6, and RM 444.2. Each site consisted of either two or three subsites (see Table 1). At each subsite, quadrats were placed approximately 1 m apart and arranged in a 2 × 5 matrix. A diver excavated all sand, gravel, shells, and live clams to a depth of 10 to 15 cm. Material was sent to the surface in a 20-L bucket and transported to shore. Sediment was screened through a sieve series (finest screen with apertures of 6.4 mm). A total of 619 unionids were collected using quantitative techniques at two sites (each with three subsites) in 1989, and 256 were collected at two sites (each with two subsites) in 1990.

All live mussels and *C. fluminea* collected in the quantitative samples were placed in 4-L zipper-lock bags, preserved in 10-percent buffered Formalin, and returned to WES. In the laboratory, each mussel was identified, weighed to the nearest 0.01 g on a top-loading balance, and measured for total shell length (SL) to the nearest 0.1 mm using dial calipers. *Corbicula fluminea* in each sample were counted, and total wet weight for all individuals was recorded. One complete sample of *C. fluminea* from each subsite was chosen randomly, and total SL of each specimen was measured.

Data analysis

Species diversity was determined with the following formula:

$$H' = -p_j \log p_j \tag{1}$$

where p_j is the proportion of the population that is of the j^{th} species (Shannon and Weaver 1949). Evenness was calculated by determining diversity on the sample while assuming that an equal number of individuals were distributed among each species (i.e., if there were 100 individuals and 10 species, each species would have 10 individuals present). Means, standard deviations, etc., were calculated using spreadsheets, or programs written in either BASIC or Statistical Analytical System (SAS) on an IBM XT or AT personal computer. Discussion of these standard statistical techniques that were used can be found in Green (1979) and Hurlbert (1984). Species area curves and dominance-diversity curves were constructed from qualitative and quantitative biological data. More information on these analytical methods can be found in McNaughton and Wolf (1973), Hughes (1986), Isom and Gooch (1986), Kovalak, Dennis, and Bates (1986), and Miller and Payne (1988).

Growth studies

In 1989 and 1990, growth studies were initiated at RM 444.2, 444.4, and 444.6 using six demographically complete groups (all size groups present) of three unionid species (*Amblema plicata*, *Quadrula metanevra*, and *Obliquaria reflexa*). For each species, shell length, shell height, and maximum body width were measured. In addition, the total number of rings (lines of growth) was counted wi   possible. Each mussel was engraved with a dremel tool with an identifying letter and number. Results of growth studies will be available after specimens are recollected in 1991.

At each location three 0.25-m^2 aluminum quadrats were cabled together with approximately 5 to 7 m of 3/8-in. coated wire rope. A diver then placed each quadrat into the substrate while excavating all sediment, live bivalves, and shells from the enclosed area. Twenty liters of screened gravel (saved from the quantitative samples) and the marked mussels were then placed in each quadrat. Total density was equivalent to 100 individuals/m^2 in each enclosure, which was about twice the density at the mussel bed. The quadrats did not contain any live *C. fluminea*. The three quadrats, and connecting cable, were parallel to shore at a distance of 100 ft. All distances were measured with an optical range finder. Exact location was determined by reference to standard features on navigation charts.

Quadrats will be relocated in subsequent years by anchoring the dive boat on the shore side of the quadrats. Divers will gradually work toward deeper water searching the substrate for the cable connecting the quadrats. It is fairly easy for a diver to find a linear feature (i.e., a length of cable) that is parallel to the shore. When the quadrats are located, the divers will excavate all substrate from each. In addition, substrate immediately outside the quadrats will be searched for previously marked mussels. All

collected sediments will be taken to shore and searched for live bivalves. All bivalves will be identified and remeasured. Mussels and sieved sediments will be replaced within each quadrat. If mussels are lost through mortality or other causes, additional specimens will be measured, marked, and placed in the exclosure.

Condition analyses

A demographically complete collection (approximately 25 specimens of all size classes present) of the species used for growth studies (*A. plicata*, *O. reflexa*, and *Q. metanevra*) were preserved for condition analysis. In addition, individuals of four species (*Truncilla truncata*, *Pleurobema cordatum*, *Quadrula pustulosa*, and *Elliptio crassidens*) from sites where quantitative samples were collected were retained for condition analysis. In the laboratory, total shell length and wet (blotted) mass were determined. The shells were then separated by cutting adductor mussels with a knife. Wet tissue and shells were placed separately in tared crucibles and dried for approximately 24 hr in an oven (65 °C) before reweighing. Measures of condition consisted of rations of tissue dry mass to shell dry mass or shell length.

Examination of tissues

Five individuals of each of the dominant species (*A. plicata*, *O. reflexa*, and *Q. metanevra*) were frozen (0 °C) at WES. In addition, five individuals of each of these three species were preserved in 10-percent buffered Formalin. Preserved and frozen specimens will be held at WES and will be available for further study. It is possible that future barge activity could result in limited coal spillage. The mantle and gill tissue of these specimens can be compared with individuals collected after coal deliveries begin. No tissue abnormalities were found in any of the mussels collected in 1989.

Sediment analyses

Divers provided qualitative information on sediment conditions at each site. This included an estimate of the percentage of sand, gravel, or silt based upon touch. At RM 444.4 and RM 444.6, divers collected four sediment samples using a hand-held benthic corer (Miller and Bingham 1987). Samples were placed in 4-L zipper-lock bags, chilled, and returned to WES. One sample was used for grain size analysis; the other three were used for determination of total organic content (i.e., loss on ignition).

Grain-size analysis is a process in which the proportion of material in each size class present is determined. A wet sediment sample is passed through a set of 19 sieves (sieve openings range from 50 to 0.025 mm). The material on each screen is dried to 105 °C and weighed. Material that

passes through the finest sieve is tested with a hydrometer that measures the silt-clay fraction (particles with a diameter between 0.025 and 0.001 mm). Results of the sieve and hydrometer analysis are expressed as a percentage of the total sample weight. Grain size analysis quantifies the relative percentages of various sized particles present. More information on the procedure for determining grain size analysis can be found in MacIver and Hale (1986).

Total organic content was determined on each of the three sediment samples. Sediments were dried at 65 °C and then weighed. The samples were then heated at 550 °C for 24 hr. The loss on ignition is a measure of organic content and is expressed as a percentage of the sample dried at 65 °C.

Water velocity

In 1989, water velocity was measured 150 and 300 ft from the RDB at RM 444.4 using two Marsh McBirney model 527 current meters. In 1990, water velocity was measured 100 ft from the RDB at RM 444.4 using the same procedures. The tip of each velocity probe was mounted in a concrete block, positioned, and secured by divers (Figure 2). Water velocity was measured 20 to 25 cm above the substrate-water interface. The sensor for this instrument measures velocity in two directions (X and Y components that are at right angles to each other) and is equipped with a compass. The compass, which is read from the meter, assists in positioning the sensor and can be used to calculate direction of flow. Each meter was equipped with a 1,000-ft spool of cable. Water velocity in two directions and the compass reading were obtained at 1-sec intervals and stored on a model CR10 data logger (Campbell Scientific, Inc., Logan, UT). In the field, all data were downloaded to a Toshiba lap-top personal computer and converted to ASCII files. Magnitude of flow was calculated from individual velocity components by the formula

$$\text{Magnitude} = (X^2 + Y^2)^{0.5} \tag{2}$$

The resolved angle of water flow was determined by the formulae:

$$0 = \tan^{-1}\frac{X}{Y} \text{ if } Y \geq 0 \text{ , or} \tag{3}$$

$$0 = \tan^{-1}\frac{X}{Y} + 180\,\text{deg, if } Y < 0 \tag{4}$$

Individual components of velocity, combined velocity, and direction of flow were plotted using a Macintosh computer and laser printer. More information on the Marsh McBirney 527 current meter and methods for calculating combined flow can be found in the instruction manual for the model 527.

Suspended solids

Water for suspended solids was collected 10 cm above the substrate-water interface at RM 444.4. Water was brought to the surface through a 25-ft length of rubber hose secured to a concrete block (Figure 3). Suction was provided by a 12-v Water Puppy pump. The pump ran continuously, and a 500-ml bottle was filled every 10 sec. A total of 20 samples were collected at each of two locations; 10 were taken 150 ft from the RDB and 10 were taken 300 ft from the RDB. Samples were returned to the laboratory on ice. In the laboratory an aliquot of water was filtered through preweighed 0.45-µ filters, dried at 105 °C, and weighed.

The gravimetric determination of suspended solids provides a measure of the mass of suspended material in the water column. It is usually weakly correlated with turbidity, a measure of the dispersion of light by particles in the water column. Suspended solids is an appropriate measure since it relates directly to impacts on filter-feeding organisms (unlike turbidity).

Water chemistry

Routine water chemistry tests (total alkalinity, total hardness, specific conductance, and dissolved solids) were measured on water collected at the surface and near the substrate-water interface at RM 444.4. Analyses were based on standard methods (American Public Health Association 1965).

3 Results

Physicochemical Conditions

Substrate

The upper one-third of the mussel bed adjacent to the Zimmer Station consisted primarily of sand and gravel; at RM 444.4 the sediments consisted of sand (73 percent) with lesser amounts of gravel (22 percent) and silt (5 percent) (Figure 4). The percentage of coarse particles in the substrate increased moving downriver. At RM 444.6 sediments consisted of gravel (77 percent) followed by sand (21 percent) and silt (2 percent). Along the lower one-third of the mussel bed the divers reported areas of exposed bedrock interspersed with gravel and sand.

At an upriver section of the mussel bed (RM 444.2), the size distribution of inorganic sediments at three distances from shore was analyzed (Figure 5). At a nearshore site (100 ft from the RDB) sand-sized particles (0.03 to 5 mm) comprised more than 50 percent by weight. At the center of the mussel bed (200 ft from the RDB) sand comprised 70 percent, with gravel (>5.0-mm diameter) and silt or clay-sized particles (0.03-mm diameter) comprising about 30 percent. At the farshore site, sand and gravel dominated, with less than 2 percent silt or clay sized particles. The lack of fine particles moving from nearshore to farshore (Figure 5) demonstrates the effects of the higher current velocities closer to the channel.

Suspended solids

Concentrations of suspended solids at the substrate-water interface at nearshore (150 ft from the RDB) and farshore (300 ft from the RDB) stations at RM 444.4 were typically less than 10 mg/L (Figure 6). These data were collected in 1989 when no commercial vessels were in the area. Similar studies will be conducted in the final phase of this work when commercial vessels are maneuvering near the mussel bed. The means (±SD) of 10 samples collected at the nearshore and farshore stations were 9.6 ±2.8 mg/L and 10.4 ±12.1 mg/L, respectively. The comparatively high

value in sample 7 (farshore station) illustrates natural variations in these data. Suspended solid concentrations were not significantly different at the two stations ($t = -0.201$, $p = 0.85$).

Water velocity - 1989 studies

Ambient water velocity (1-sec intervals) at the substrate-water interface for both nearshore and farshore stations at RM 444.4 are displayed in Figures 7 and 8, respectively. These data were taken when no commercial traffic was in the area; additional data were collected in 1990 as commercial vessels passed the site (see below). Mean water velocity parallel to flow (facing upriver) was slightly greater 300 ft from the shore (0.887 ft/sec) than at the nearshore station (0.771 ft/sec) (Table 2). The range and standard deviation were higher at the farshore than at the nearshore station. Mean combined velocities (considering both velocity components) were 0.800 ±0.112 and 0.893 ±0.112 cfs at the nearshore and farshore stations, respectively. Direction of flow ranged from 8.9 to 47.7 deg and 26 to 349 deg at the nearshore and farshore sites, respectively (0 and 360 deg correspond to due north, whereas 180 deg corresponds to due south). The Ohio River flows north at this location.

Water velocity - 1990 studies

In 1990, water velocity near the substrate-water interface was measured under ambient conditions (no vessels present, Figure 9) and as four commercial vessels passed (Figures 10-13, Table 3). Sensors were 100 ft from the RDB. The means of 200 sec of ambient velocity data (Figure 9) parallel and at right angles to flow (0.795 ft/sec and 0.196 ft/sec) were similar to data collected at the nearshore site in 1989 (0.771 ft/sec and 0.199 ft/sec) (compare Tables 2 and 4). Downbound passage of a loaded vessel (Event 1, Figure 10), 900 ft from the RDB, caused a slight but measurable change in water velocity on the Y and X axes. However, standard deviation and range (maximum-minimum values) for 200 sec of data were similar to those under ambient conditions, indicating that this passage had a minor effect. The combined velocity was affected to a greater extent than individual velocity components, although direction of flow was unaffected (Figures 10b and 10c). Upbound passage of an unloaded vessel appeared to have little effect on ambient water velocity (Figure 11, Table 4). Downbound passage of an unloaded vessel caused an abrupt decrease in velocity of about 0.5 ft/sec immediately after the front of the tow passed the sensor. A gradual decrease in ambient velocity approximately 100 sec after the vessel passed was caused by water displacement from the barges. The lowest minimum velocity value for any commercial vessel passage was measured during Event 3. Velocity at right angles to flow declined to a minimum of -0.394 ft/sec as the vessel passed the sensor. A minor direction change was also noted (Figure 11). The final event (No. 4), an upbound unloaded tow consisting of 13 barges, caused a minor current reduction immediately prior to vessel passage

(Figure 13). However, for this and the previous three events, the physical changes brought about by vessel passage are overshadowed by normal velocity fluctuations.

Chemical conditions

Water quality in the Ohio River at Markland L&D (RM 531.5, approximately 90 miles upriver of the Zimmer Station) can be described as hard, with fairly high nutrient levels. On 26 July 1989 the following data were recorded at Markland L&D: total hardness (142 mg/L as calcium carbonate), sulfate (55 mg/L), total phosphorus (0.15 mg/L), nitrate nitrogen (0.66 mg/L), iron (1,500 µg/L), biological oxygen demand (1.6 mg/L), and suspended solids (26 mg/L) (ORSANCO 1989). Average discharge for the day was 61,200 cfs. Basic chemical data collected at RM 444.4 (Table 5) on 22 July 1989 indicate that the water at this site is well mixed and differs little from that reported at Markland L&D by ORSANCO (1989). Carbonates and sulfates in this river reach are the result of limestone deposits in the watershed. Nitrogen, phosphorus, and other nutrients originated either from industrial or nonpoint source inputs.

The Bivalve Community

Community composition

Twenty-five species of unionids, in addition to the Asiatic clam *Corbicula fluminea*, were collected using qualitative techniques at nine sites (Table 6). Three species (*P. cordatum*, *Q. metanevra*, and *Q. pustulosa*) were abundant and comprised 54.7 percent of 1,798 individuals collected. Ten species were common, and each comprised 10.0 to 1.5 percent of the unionid fauna. The remaining 12 species were uncommon, and each comprised less than 1 percent of the assemblage. Only a single *Lampsilis abrupta* (designated as endangered by the US Fish and Wildlife Service) (USFWS 1987) and *Anodonta grandis* were collected.

Each of the three most common native bivalve species was found in more than 74 percent of the 108 samples (Table 6). Fourteen species were found in 73.1 to 10.2 percent of the samples, and eight species were taken in less than 10 percent of the samples. Mussel species were evenly distributed in this assemblage (Figure 14).

Difference in relative species abundance with respect to river mile were minor (Figure 15). *Elliptio crassidens* represented a greater percentage of the assemblage moving downriver, whereas abundances of *Megalonaias nervosa* and *Pleurobema cordatum* were only slightly greater at the downriver sites (Figure 15a). *Obliquaria reflexa* and *Quadrula metanevra* were slightly more common in the midportion of the mussel

bed, although there were no notable trends for *Amblema plicata* (Figure 15b). *Leptodea fragilis* and *Potamilus alatus* were uncommon at most sites, and *Quadrula pustulosa* abundances ranged from 11.3 to 26.5 percent and exhibited no specific trends with respect to river mile (Figure 15c and Table 7). Although there was minor variation in relative species abundances among most sites, species diversity (H′), evenness (J), and dominance were comparable at all sites (Figure 16).

The relationship between cumulative species and cumulative individuals collected graphically illustrates the amount of effort required to obtain uncommon species. Figure 17 indicates that a sample of 168 to 215 individuals yielded 16 to 18 species. In a sample of 200 mussels, one individual of the least common species would comprise 0.5 percent of the fauna. At this mussel bed, 18 species comprised more than 0.5 percent of the assemblage (Table 6). Therefore, a collection of 200 individuals is sufficient to obtain common and fairly common unionids and should yield about 18 species. Considerably more effort would be required to obtain uncommon species. By increasing the sample of 200 individuals to 1,798 (by grouping all nine qualitative samples, Figure 18b), eight more species were obtained (Figure 17b). A ninefold increase in sample size resulted in only a 28-percent increase in species richness.

Density

Total unionid density ranged from a low of 4.4 individuals/m^2 at the upriver site at RM 44.2 to a high of 52.4 at RM 444.6 (Table 8, Figure 18). Unionid densities among sites were variable, and significantly different ($F = 6.7$, $p < 0.0001$). At RM 444.2, average unionid density was about 50 percent less than farther downriver. Total density of C. fluminea ranged from a low of 66.6 individuals/m^2 to a high of 1,352 individuals/m^2 ($F = 63.7$, $p < 0.001$). Densities of C. fluminea were substantially less at upriver subsites (RM 444.2) than at RM 444.4 or 444.6. Of the most common species, only *O. reflexa* exhibited a significant density difference between the two downriver sites ($t = 2.06$, $p < 0.05$). The mean and standard deviation for this species at RM 444.4 and RM 444.6 was 2.8 ± 3.3 and 4.8 ± 4.1 individuals/m^2, respectively. *Corbicula fluminea* outnumbered native unionids by 33 and 20 times at RM 444.4 and RM 444.6, respectively. At sites 444.2-u and 444.2-d, native unionids outnumbered *C. fluminea* by 5.7 and 27.6 times, respectively (Table 8).

Twenty-one species and 344 individuals were collected at RM 444.4, and 20 species and 275 individuals were collected at RM 444.6 using quantitative techniques (Table 9, Figure 19). The quantitative samples included *Truncilla donaciformis*, a small species that was missed using qualitative techniques. Four species (*T. truncata*, *L. abrupta*, *Lasmigona costata*, and *Elliptio dilatata*) were collected qualitatively but were not found in the quantitative collection. The qualitative collection contained approximately twice the number of individuals as the quantitative collection;

therefore, it provided more opportunity to obtain uncommon species. Estimates of relative species abundance differed between the quantitative and qualitative collection. For example, the four most abundant species in the qualitative collection at RM 444.4 were *Q. metanevra* (33.33 percent), *A. plicata* (13.10 percent), *Q. pustulosa* (11.31 percent), and *P. cordatum* (10.71 percent) (Table 7). Based on quantitative techniques, the four most abundant unionids at this site were *Q. pustulosa* (28.87 percent), *P. cordatum* (16.57 percent), *O. reflexa* (10.47 percent), and *Q. metanevra* (8.14 percent) (Table 8). A qualitative collection will always differ slightly from a quantitative collection; usually the latter contains a higher percentage of relatively small individuals. Total number of individuals collected, species richness, species diversity, and evenness were similar at RM 444.4 and RM 444.6. Species area curves for both sites were also similar (Figure 20). The numbers of individuals and species less than 30 mm total SL were similar at both sites (Table 9). Although total unionid density was slightly less at RM 444.2 than at the two downriver sites, total species richness was similar among all sites (compare Tables 9 and 10). Other community biotic indices (dominance, diversity, and evenness) were similar among sites. Evidence of recent recruitment (unionids less than 30 mm total SL) was considerably less at RM 444.2 (22.2 percent and 10.3 percent) than at the two downriver sites (52.4 percent and 50.0 percent).

Total biomass (i.e., shell plus wet tissue) of unionids was approximately 25 to 50 percent of the total biomass for *C. fluminea* (Table 11). Average biomass of unionids was greater at RM 444.6 ($4,414.8 \pm 2,566.8$ g/m^2) than at RM 444.4 ($2,422.9 \pm 2,017.7$ g/m^2). However, since recruitment rates and density were not significantly different between these two sites, these differences were due mainly to the presence of a few large unionids. Only two species of common unionids, *P. cordatum* ($t = -3.33$, $p < 0.05$) and *O. reflexa* ($t = -2.4$, $p < 0.05$), exhibited significant differ-ences in biomass between the two downriver sites. At RM 444.4 and RM 444.6, the mean and standard deviation for *O. reflexa* were 106.3 ± 139.4 g/m^2 and 220.7 ± 225.2 g/m^2, respectively, and the mean and standard deviation for *P. cordatum* were 455.7 ± 562.7 g/m^2 and 938.1 ± 627.2 g/m^2, respectively. Average biomass of *C. fluminea* was significantly greater ($p < 0.0001$) at RM 444.4 ($5,243.7 \pm 1,174.7$ g/m^2) than at RM 444.6 ($3,557.1 \pm 674.3$ g/m^2). Total biomass of *C. fluminea* at RM 444.2-u was significantly less ($p < 0.0001$) than at the downriver sites (Table 11). The subsites at the four sites were significantly different with respect to biomass of unionids ($p < 0.0001$). Unionid density at only a single subsite at RM 444.2-u was significantly less than the other subsites.

The density and biomass of *C. fluminea* and unionids based on quantitative collections at the two sites were compared. There was no significant correlation between density of unionids (Y) and density of *C. fluminea* (X) (Figure 21a). In addition, there was no significant relationship between biomass of unionids (Y) and biomass of *C. fluminea* (X) (Figure 21b).

Condition analysis for *C. fluminea*

An analysis of clam condition requires determining relationships between SL, the components of shell dry mass (SDM), and tissue dry mass (TDM). The relationship of SL to SDM and TDM can be species-specific and is sometimes distinctive between populations within a species. Shell mass is nonliving material that is not removed until death although small quantities can be lost by erosive action of high water flow. Tissue mass represents most of the energy (caloric) component of the standing crop biomass of standard ecological studies. The relationship between shell mass and tissue provides an index of the relative robustness of the tissue and shell for a species population. These relationships are important baseline indicators of condition. The ratio of tissue mass to shell length can vary seasonally or with respect to reproductive condition. The ratio of shell mass to shell length can be affected by calcium content of the water, or by erosion, which usually is more noticeable in older animals. These condition indices reflect the overall health of a population since they can be affected by environmental disturbance.

Shell length was positively correlated with growth and age of *C. fluminea*. The relationship between shell length and dry mass (Figure 22a) was not significantly different between sites ($p > 0.05$, analysis of covariance). The regression equations for TDM and SL were not significantly different ($p > 0.05$ analysis of covariance) between sites (Figure 22b). The relationships between shell mass (SDM) and tissue mass (TDM) for *C. fluminea* (Figure 22c) were not significantly different ($p > 0.05$, analysis of covariance).

Because the slopes of these lines are less than 1.0 (0.84 and 0.77), in larger animals the increase in TDM is proportionately less than the increase of SDM with respect to SL. There are no differences in these condition relationships for *C. fluminea* at RM 444.4 and RM 444.6.

Condition analysis of freshwater mussels

Baseline data on physical condition (ratios of tissue dry mass to shell length and shell mass) were obtained for a size series of three species (*A. plicata*, *Q. metanevra*, and *O. reflexa*). Representatives of these three species were used for the growth studies at RM 444.4 and RM 444.6. Baseline information on physical condition will be used for future comparisons with mussels held in exclosures. If commercial vessel movement causes substrate scour, then shells could be eroded, and relationships between shell length and shell mass could vary from baseline conditions. If increased frequency of turbulence at the substrate-water interface negatively affects respiration and metabolism of individual mussels, then relationships between shell mass (or length) and tissue mass could be negatively affected (see Payne and Miller 1987).

The relationships between shell length and tissue and shell dry mass are given in Figures 23-25 for *A. plicata*, *Q. metanevra*, and *O. reflexa*. Within each species the slopes of the regressions of SDM and TDM to shell length were not significantly different ($p > 0.05$, analysis of covariance). As shell length increased, shell mass and tissue mass increased to approximately the third power. (As the length of an object increases, its mass increases to the third power.) Mass-to-mass comparisons (or length-to-length comparisons) are directly proportional (i.e., vary to a power of 1). There were significant relationships between tissue dry mass and shell dry mass for these three species (see Figures 26a-26c) with expected slopes essentially equal to 1 (0.98, 1.06 and 0.97, respectively).

Relationships among shell thickness, shell mass, and body size can relate to substrate preference and water flow dynamics. An examination of regressions for SDM versus SL provides information about these relationships. In the equation,

$$SDM = aSL^{b} \tag{5}$$

where

a = SDM of a clam with a shell length of 1 mm

b = slope of the relationship

A comparison of the three unionids illustrates that at a shell length of 1 mm, *A. plicata* has the heaviest shell (greatest a-value). However, *O. reflexa* has the greatest increase in SDM as SL increases (greatest b-value). The maximum size of *O. reflexa* was less than for the other unionids. The rapid increase in SDM with respect to SL for this species is probably related to shape; *O. reflexa* has a larger cavity volume than the other two species.

A comparison between shell length and tissue dry mass and shell length and shell dry mass at RM 444.4 and RM 444.6 was made for *T. truncata*, *Q. pustulosa*, *P. cordatum*, and *E. crassidens* (Figures 27-30). The correlation coefficients for both relationships for the first three species are greater than 0.90; in addition, no significant differences between RM were found (analysis of covariance). Correlation coefficients relating shell and tissue measurements for *E. crassidens* were not significant ($R \leq 0.7$) between sites. Low correlations were the result of a small sample (this species was uncommon, see Table 6), and most individuals were about the same size.

As these data illustrate, there were no significant differences in condition between unionids or *C. fluminea* collected at RM 444.4 and RM 444.6. Although condition indices can be affected by water velocity and substrate, at this mussel bed intersite differences were relatively minor. However, the purpose of this study was to collect baseline data that will be used to evaluate environmental change.

Demographic analysis of *C. fluminea*

The size distributions of *C. fluminea* from quantitative samples taken at RM 444.4 and 444.6 are given in Figure 31. Each distribution represents the combination of data from three of thirty 0.25-m^2 quadrats collected at each site. Four or five cohorts are represented in these distributions. *Corbicula fluminea* can have one or two cohort recruitments each year. It is therefore impossible to confidently assign year classes to these distributions since each population responds to its environment, and specifics of its life cycle at this location are not known. The two distributions for the two sites are similar.

Demographic analysis of dominant unionids

It is difficult to provide a detailed interpretation of population characteristics for common unionids with only one or two years of quantitative data. Additional sampling would provide a stronger basis for a discussion of population dynamics. *Quadrula pustulosa* exhibited moderate evidence of recent recruitment (Figure 32). About 5 percent of the population consisted of individuals less than 20 mm total SL; these individuals were probably 2 years old. A second group, between 24 and 38 mm, comprised about 20 percent of the population and probably consisted of two cohorts. Approximately 70 percent of the *Q. pustulosa* was made up of individuals greater than 40 mm total SL. This group probably consisted of four or more cohorts that could not be easily distinguished.

Pleurobema cordatum exhibited a bimodal size distribution with missing size class between 58 and 62 mm (Figure 33). At RM 444.4, approximately 70 percent of the population was less than 56 mm total SL and probably consisted of at least four cohorts. At RM 444.6, approximately 70 percent of the *P. cordatum* were greater than 64 mm. Only 2 percent of the population consisted of individuals less than 30 mm total SL.

Obliquaria reflexa exhibited low recruitment; about 3 percent of the population was 30 mm total SL or less (Figure 34). Less than 10 percent of the population was greater than 58 mm total SL. The majority of the population consisted of three or four closely spaced cohorts.

Truncilla truncata, which rarely exceeds 50 mm total SL, consisted of three cohorts (Figure 35). A single cohort consisted of individuals less than 19 mm; the second cohort consisted of individuals between 20 and 28 mm; and the third, of individuals greater than 30 mm. Only 4 percent of the *Q. metanevra* were less than 32-mm total SL (Figure 35). The remainder consisted of four or five closely spaced cohorts. *Amblema plicata* exhibited a fairly even size distribution (Figure 35). About 14 percent of the population was less than 25 mm; this cohort was probably 2 years old. Three or four cohorts (between 37 and 71 mm total SL) made

up approximately 65 percent of the population, and 21 percent of the population was between 82 and 102 mm total SL.

Length-frequency histograms for *C. fluminea*, *Q. pustulosa*, *O. reflexa* (Figure 36) and *Q. metanevra* and *A. plicata* (Figure 37) were developed from 1990 data collected at RM 444.2. Direct comparison of these findings with demographic data collected in 1989 at RM 444.4 and RM 444.6 may not be valid. Substrate as well as the biota at RM 444.2 may have been disturbed by construction and placement of mooring cells. These data can, however, be used to assess environmental effects of barge deliveries at RM 444.2.

Corbicula fluminea at RM 444.2 was characterized by dominance of mid-sized individuals (26 mm). *Corbicula fluminea* at RM 444.4 and RM 444.6 (Figure 31) exhibited a more even distribution of cohorts. Length-frequency histograms for the other species at RM 444.2 (*Q. pustulosa*, *O. reflexa*, *Q. metanevra*, and *A. plicata*) were characterized by multiple cohorts and were similar to those constructed for these species at RM 444.4 and RM 444.6.

4 Discussion

Monitoring the Effects of Commercial Navigation Traffic

The continued use of inland waterways to transport bulk commodities (Dietz et al. 1983) has caused planners and biologists in government agencies to express concern over the possible negative effects of commercial traffic (Rasmussen 1983). The physical effects of commercial vessel movement include wave wash, turbulence, benthic scour, drawdown, current reversals, and periods of increased sediment resuspension (Wright 1982). Freshwater mussels, a resource with economic, ecological, and cultural value, could be affected by these disturbances. Their sedentary lifestyle and reliance on suspended particulate organic matter make them susceptible to turbulence, sedimentation, and fluctuating water levels.

Although some physical effects of commercial traffic can be partially simulated in the laboratory (Morgan et al. 1976; Holland 1983, 1986; Stevenson et al. 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller and Conley 1987; Payne and Miller 1987; Way et al. 1989; Payne, Killgore, and Miller 1991), caution must be exercised when using results from these studies to estimate impacts to natural populations. Responses noted in the laboratory may not occur in the field. In addition, naturally occurring compensatory mechanisms usually exist that may not be part of laboratory experiments.

Planners and biologists must evaluate the effects of man's activities on populations of species in their natural habitats. As an alternative to laboratory simulation, field studies should be conducted to evaluate the biological effects of tow-induced disturbances. Field studies must be designed to provide quantitative data on biotic parameters such as density, relative species abundance, community composition, population demography, and rate of growth. These data cannot be obtained with exploratory devices such as the brail, or by qualitative collections by hand (Miller and Payne 1988). Quantitative total substrate samples provide the type of data required to measure the overall health and ultimate survival of a mussel community.

Baseline information on aquatic resources at the mussel bed immediately downriver of the Zimmer Station was obtained in 1989-90. Data were collected on relative species abundance, density, biomass, and population structure of dominant bivalves at nine sites in the bed. Quantitative data were obtained at RM 444.2, immediately downriver of the last mooring cell, and at RM 444.4 and RM 444.6, located farther downriver. In addition, information on water velocity and suspended solid concentrations was collected near the substrate-water interface at RM 444.4.

After the barge-loading facility has operated for a year or more, additional data on bivalves will be obtained. An analysis of the effects of commercial traffic will be based on an evaluation of physical and biotic parameters before and after coal deliveries by barge. The design for these postoperation studies will be the same as for the baseline study. Biotic conditions at study sites did not differ dramatically from one another; therefore, results of Phase III work will not be confounded by intersite variability.

The Bivalve Community

Extent of mussel bed near Zimmer Station

Based on results of the baseline survey, the majority of the mussels were found in water 20 ft deep and 100 to 220 ft from shore. Qualitative searches indicated that this bed was restricted to a narrow band along the shore; high-density mussel populations were not found more than 300 ft from the RDB. Water velocity at the substrate-water interface 300 ft from shore was slightly greater (0.887 ft/sec) than 150 ft from shore (0.771 ft/sec). It is likely that higher water velocities at the outer edge of the bed create conditions that are inimical to long-term survival of mussel populations. Juveniles cannot settle and burrow effectively in substrate exposed to high-velocity water. Intermediate-sized and adult mussels, once established, are stressed by continual exposure to high-velocity water.

Other investigators have reported that dense mussel beds occur along the borders of river channels where water velocities are reduced. In a bed in the lower Tennessee River, Way, Miller, and Payne (1990) found significantly higher densities of mussels at depositional nearshore sites than at more erosional sites farther offshore. In the lower Ohio River near Olmsted, IL, mussels were not found in the main channel but were restricted to a gravel shoal near shore (Payne and Miller 1989). In Pool 10 of the upper Mississippi River, mussels were found in the main channel, although densities were usually an order of magnitude less than along the channel border (Duncan and Thiel 1983; Miller and Payne, unpublished information).

Species richness

Stansbery and Cooney (1985) collected mussels at this site with the brail, by diving in deep water, and by wading in shallow water and along the shore. They obtained 2,431 individuals and found 29 species. However, by deleting three lentic species that Stansbery and Cooney collected along the shore, but that were not found in the present survey (*Anodonta suborbiculata, P. alatus,* and *Toxolasma parvus*), lists from both surveys are nearly identical. From the current survey 25 species were collected, and previous workers reported 24 species. A single *L. abrupta* not collected by Stansbery and Cooney (1985) was obtained. Although sampling techniques differed in both studies, estimates of total species richness and community composition were similar.

Total species richness at the mussel bed near the Zimmer Station is similar to that at other mussel beds in large rivers. Using similar tech-niques, Payne and Miller (unpublished information) identified 24 species at a dense mussel bed in the lower Tennessee River. A total of 29 and 23 species of unionids were collected at a site in Pool 10 of the upper Mississippi River and in the lower Ohio River near Olmsted, IL, respectively (Miller and Payne 1988, Payne and Miller 1989). In a survey of the upper Mississippi River, Miller et al. (1990) collected over 15,000 bivalves in 667 qualitative samples at 58 locations and identified 34 species. However, total species richness at any one location was usually between 15 and 25. Smaller rivers usually support fewer species. Using quantitative techniques at dense beds in the Sunflower River and Big Black River in central Mississippi, 13 and 15 species were identified, respectively (Miller and Hartfield, in preparation; Payne and Miller, unpublished information).

Relative species abundance

This mussel bed can be characterized as having a relatively even distribution of unionid species (i.e., evenness values that approach 1.0). The numerically dominant unionid at RM 444.6, *Q. pustulosa*, comprised 28.8 percent of the fauna. By comparison, at a dense bed in Pool 10 of the upper Mississippi River, the numerically dominant unionid, *A. plicata*, comprised 67.1 percent of the assemblage. In the lower Tennessee River the mussel fauna was dominated by *Fusconaia ebena*, which comprised 73.0 percent and 54.8 percent of the fauna at a nearshore and farshore site, respectively (Way, Miller, and Payne 1990). The mussel bed at the Zimmer Station did not have a clear dominant (i.e., a species that comprised more than 50 percent of the assemblage) as in the previously described mussel beds. Evenness at this mussel bed (0.80 and 0.76 at RM 444.4 and RM 444.6, respectively) was approximately double that at two nearshore sites in the lower Tennessee River (0.392 and 0.384).

General characterization of the unionid assemblage

The mussel bed downriver of the Zimmer Station consisted almost entirely of thick-shelled gravel bar species. The fauna was dominated by *Quadrula* sp., *Pleurobema* sp., *M. nervosa.*, and *Elliptio* sp. Thin-shelled and moderately thick-shelled species (*L. fragilis*, *P. alatus*, and *Lampsilis ventricosa*) each comprised less than 1 percent of the qualitative collection (Table 6). Within their range, these latter species cannot be considered rare or uncommon in large rivers; each has multiple fish hosts (Fuller 1974) and would be more common if suitable conditions of substrate and water velocity existed. However, coarse gravel substrate and erosive flows at high discharge can stress thin-shelled species. If present, few are likely to reach adult size.

Three uncommon species were found at this bed in 1989. *Lampsilis abrupta* (=*orbiculata*), listed as endangered by the US Fish and Wildlife Service (1987) and the Commonwealth of Kentucky (Branson et al. 1981), has not been reported from this site by previous workers. Although uncommon, this species has not been extirpated from the Ohio River; Tolin, Schmidt, and Zeto (1987) reported finding it in the Ohio River bordering West Virginia. Historically this species was uncommon over a wide area and was found in the Niagara River at Buffalo, NY; the Illinois River in Illinois; the lower and upper Ohio River and some of its tributaries (Allegheny, Monongahela, Kanawha, Muskingum, Scioto, Green, Wabash, and White Rivers); the Cumberland River and a tributary (Obey River); and the Tennessee River and some of its tributaries (Clinch, Holston, French Broad, Flint, and Duck Rivers and Limestone Creek). Currently it is still found in the Ohio, Muskingum, Green, and Cumberland Rivers, the Black and Current Rivers in Arkansas, and in the lower Tennessee River (Clarke, unpublished information).

Plethobasus cyphyus, listed as endangered by the Commonwealth of Kentucky (Branson et al. 1981), but not on the Federal List of Endangered Species, was collected using qualitative and quantitative techniques in 1989. This species comprised 1.52 percent of the qualitative collection (Table 6) and 0.29 to 2.0 percent of the quantitative collection (Tables 8 and 9). It has been found in a dense and diverse bed in the lower Ohio River near Olmsted, IL (Payne and Miller, unpublished information), and comprised 0.19 percent of the fauna at a site stabilized by wing dams in Pool 10 of the upper Mississippi River (Miller 1988).

Two *L. costata* (one in 1989 and one in 1990) were taken in the qualitative collection at RM 445.6 (Table 6). Stansbery and Cooney (1985) reported finding one specimen, although this species was not found at this bed by other workers. This uncommon mussel was reported to inhabit sand and gravel substrate in small to large rivers in the Mississippi drainage in the Midwest (Murray and Leonard 1962, Parmalee 1967).

Density

In comparison with other large-river mussel beds, unionid density (36.7 and 45.9 individuals/m^2 at RM 444.4 and RM 444.6, respectively) can be considered low to moderate. Densities at RM 444.2 (19.8 and 26.6 individuals/m^2) were about 50 percent less than those downriver. Presumably this was the result of substrate disturbance when the mooring cells were placed. At inshore and offshore sites in the lower Tennessee River (32 quantitative samples were collected at each), total mussel density was 187.7 and 79.7 individuals/m^2, respectively (Payne and Miller, unpublished information). In the lower Ohio River near Olmsted, IL, total unionid density ranged from 9 to 47 individuals/m^2 at a series of sites. In a survey of the upper Mississippi River, Miller et al. (1990) reported that total mussel density ranged from 5.2 to 333.2 individuals/m^2 at 16 sites (10 quantitative samples were taken at each). At half of the sites, total density was greater than 50 individuals/m^2 and at four sites it was greater than 100 individuals/m^2. In the Big Black River in central Mississippi, unionid density was 84.4 and 112.0 individuals/m^2 at the upstream and downstream slope of a gravel shoal, respectively (Payne and Miller, unpublished information).

Stansbery and Cooney (1985) reported that shells of *C. fluminea* were more common than those of unionids along the shore at the Zimmer site. Those workers did not estimate densities of *C. fluminea*; therefore, it is not possible to determine if this species is increasing or decreasing in abundance at this site. Based on surveys conducted in the 1960's, Williams (1969) concluded that the Asiatic clam was the most abundant bivalve in the lower Tennessee River. However, in 1986, Payne and Miller (unpublished information) found that native unionids outnumbered *C. fluminea* by factors of 84 and 40 at offshore and inshore sites, respectively, at a mussel bed in the Tennessee River (RM 18.6).

Relationship between native and nonnative bivalves

Corbicula fluminea outnumbered native unionids by factors of 33 and 20 at RM 444.4 and RM 444.6, respectively. The biomass of *C. fluminea* was 2.2 times greater than unionids at RM 444.4, although at RM 444.6 the biomass of native unionids was 1.2 times greater than *C. fluminea*. However, results of quantitative sampling did not reveal significant relationships between density or biomass of these two bivalve groups (Figure 21). Competition between *C. fluminea* and native unionids has been reviewed by McMahon (1983). Careful monitoring will be necessary to establish whether there are relationships between *C. fluminea* and native unionids.

Demography

Data from one or two collections are not sufficient for detailed analysis of recruitment and growth of a population. However, additional demographic data from this mussel bed will provide the basis for future analysis of commercial traffic effects. These populations were characterized by a large number of intermediate-sized animals and moderate to low numbers of juveniles and adults. All populations had multiple age classes and showed evidence of recent and consistent (probably every year or every other year) recruitment. This is an indication of stable substrate and suitable water level and velocity at the time of reproduction. There were no differences in the population structure of dominant bivalves collected in 1989 between RM 444.4 and RM 444.6.

None of the unionids appeared to have exhibited a period of massive recruitment in the recent past. At a dense bed in the lower Ohio River, Payne and Miller (1989) reported that 71 percent of the dominant species, *F. ebena*, belonged to a single cohort with an average SL of 15.8 mm. Unionid species at the Zimmer site in this size category usually comprised 20 percent (or less) of the population. A single population (*P. cordatum*) displayed a bimodal distribution. Single populations with a bimodal distribution are not an uncommon feature in mussel communities. In Pool 10 of the upper Mississippi River, Miller and Payne (1988) reported a bimodal distribution for *A. plicata* with a missing size class between 40 and 60 mm total SL.

Future Considerations

The barge-loading facility at the Zimmer Station began operations in 1990. Postoperation studies, to be conducted at an appropriate time after the facility is operational, will be initiated to assess the effects of barge deliveries on mussels. A complete description of Phase III studies appears in Miller, Payne, and Way (1989). The following is a brief description of tasks that could be completed during Phase III.

Analysis of population and community parameters

Additional information on size demography, density, and biomass of unionids and *C. fluminea*, collected after the barge facility becomes operational, will be used to assess environmental effects.

Estimates of growth

Results of this task will provide the following:

a. Size-specific growth rates for *Q. metanevra*, *A. plicata*, and *O. reflexa*.

b. An estimate of size-specific mortality. This will be based on the number of dead organisms (i.e., marked shells) that are found in or immediately outside the exclosures.

c. An estimate of the rate of recolonization of clean substrate. Unmarked bivalves found in exclosures will have originated from either recent recruitment or emigration of larger animals.

Variation in water velocity above and at substrate-water interface

Baseline data on water velocity 10 cm above the substrate-water interface were obtained in 1989 and 1990. Additional water velocity data can be collected at specific locations on the mussel beds as commercial vessels approach the loading facility. These data will be used to assist in interpretation of biological data and to assess effects of commercial traffic.

Summary

Pygott et al. (cited by Brookes and Hanbury 1990) studied fish community structure in four British canals where traffic events ranged from 500 to 10,000 movements per year. Heavily trafficked waterways with high turbidity had the lowest fish species diversity. Murphy and Eaton (1983) reported that low traffic levels (less than 2,000 passages per year) had little effect on abundance and composition of aquatic plant communities. When the number of events exceeded 2,000 per year, the plant communities were negatively affected by water turbulence, turbidity, and suspended sediments.

Conservation agencies in the US Federal and State governments have expressed concern over the environmental effects of commercial vessel movement. This has resulted in the publication of many reports, some speculative and without substantial data. (For a discussion of this problem, see Wright 1982.) Part of the problem is the extreme difficulty and expense of conducting field studies on traffic effects. Many species of freshwater mussels (and many fish species) live 20 or more years. At a minimum, definitive cause-and-effect studies should span a sizable segment of the species' life cycle.

Results of heavily trafficked waterways in Europe (Murphy and Eaton 1983, Brookes and Hanbury 1990) and laboratory experiments by Payne and Miller (1987) suggest that extremely high traffic intensities would be needed to affect certain aquatic organisms. Although laboratory experiments provide insight into possible impacts of physical stress to natural populations, definitive empirical data can be obtained only by long-term field studies. Predictions on the impacts of controlled use of natural resources should not be based on the results of a single laboratory experiment or on one-time field observations. Key biotic parameters should be regularly monitored, similar to the manner in which data are assembled on river discharge, precipitation, or air temperature.

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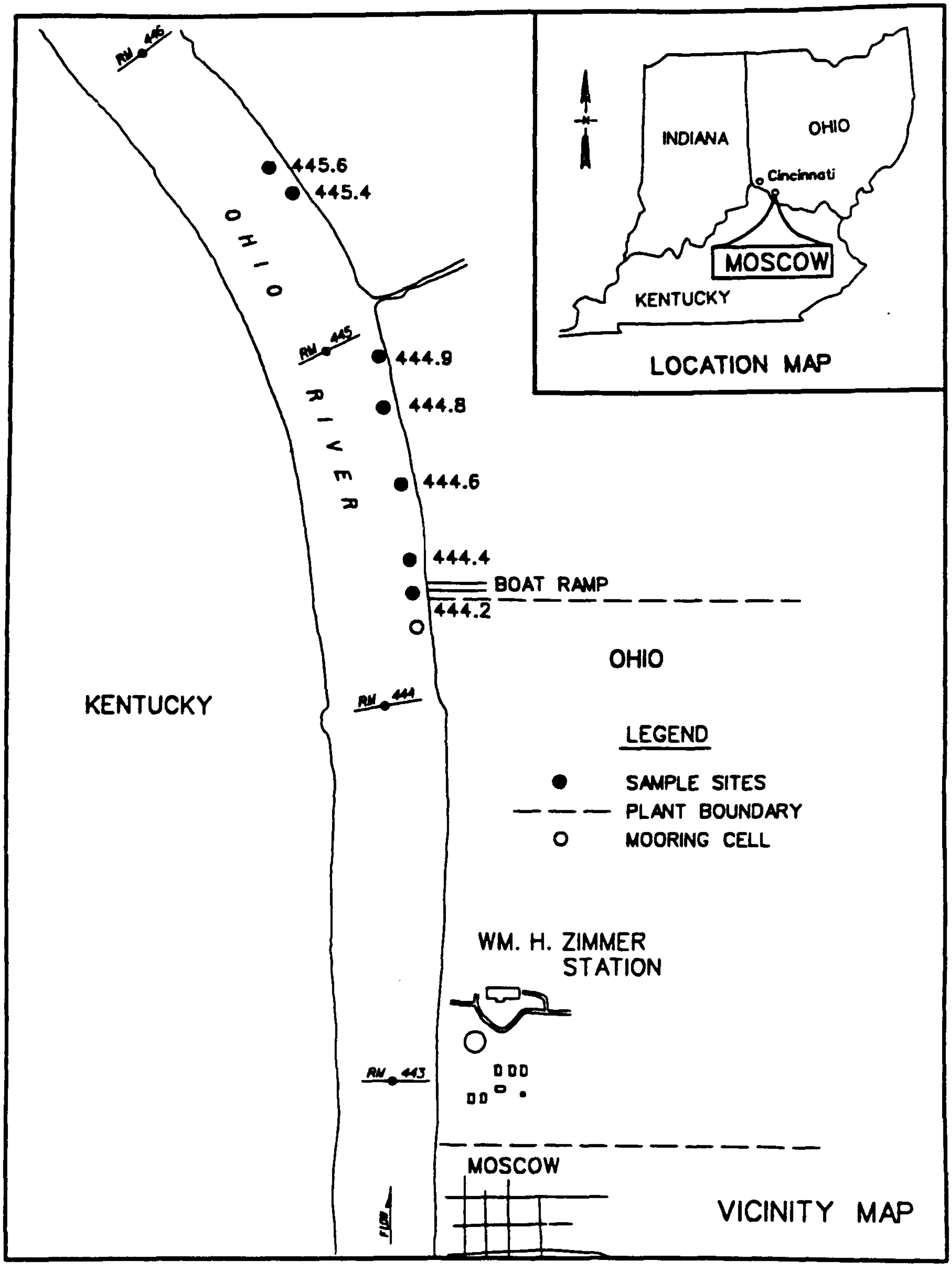


Figure 1. Map of study area on the Ohio River showing the location of qualitative and quantitative collecting sites (after Stansbery and Cooney 1985)

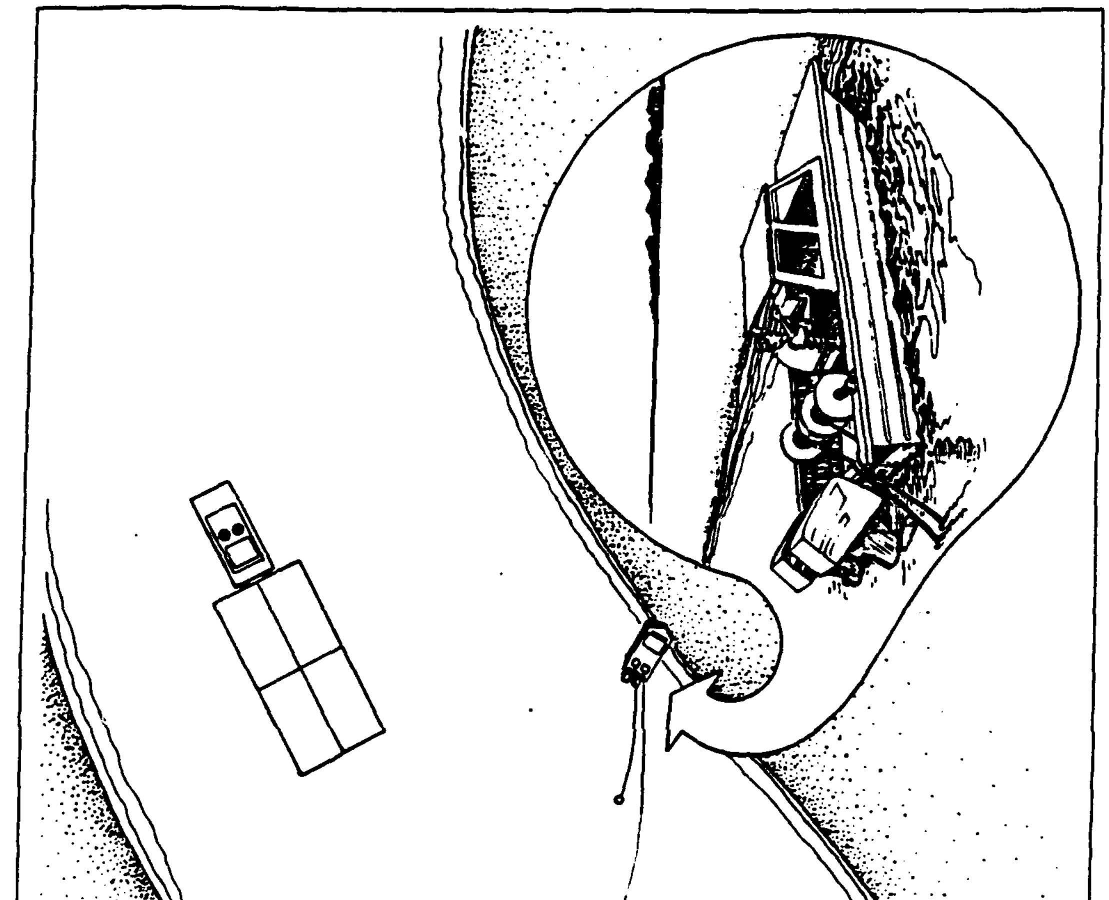


Figure 2. Velocity probes for Marsh McBirney model 527 water velocity meters

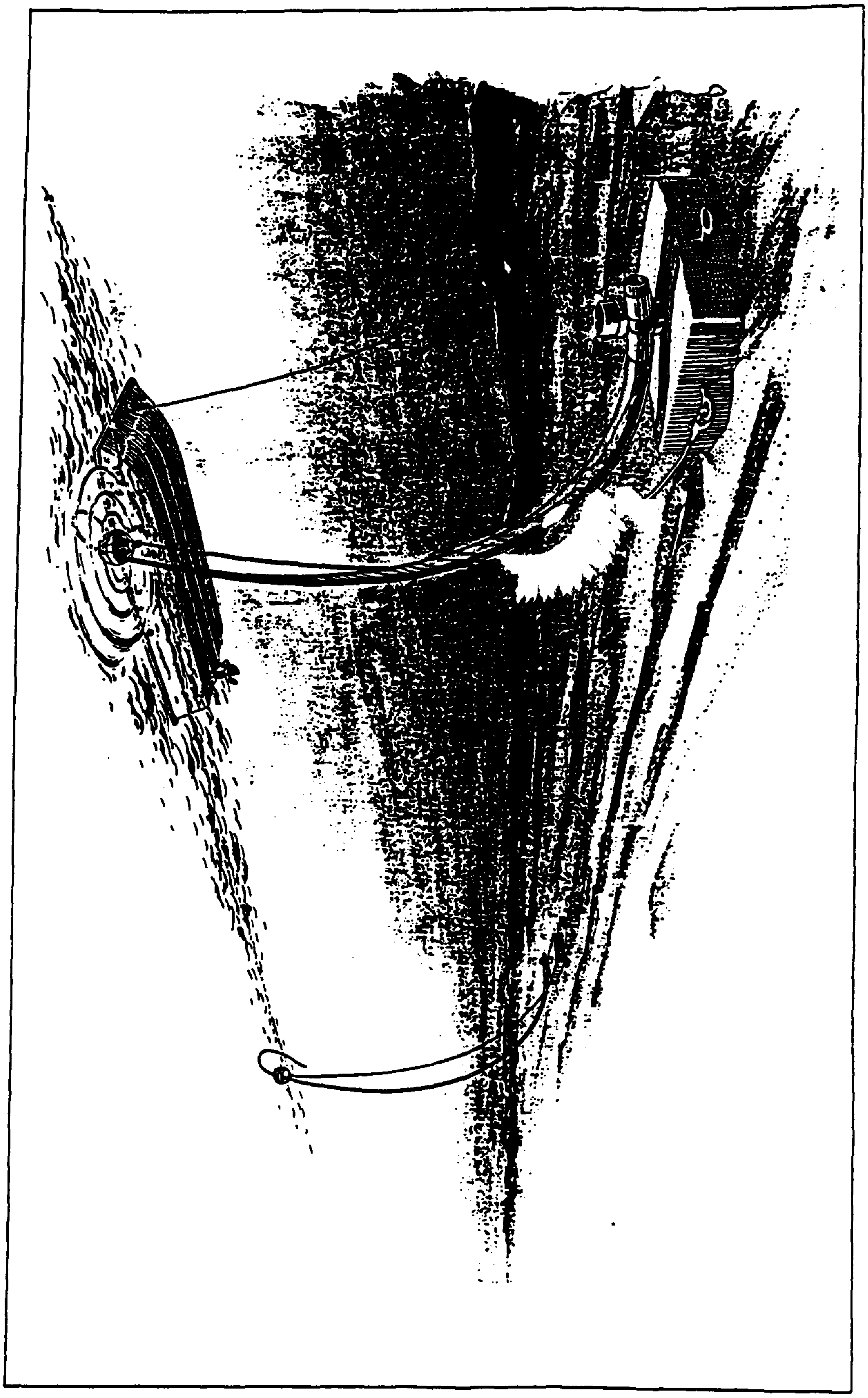


Figure 3. Apparatus to collect suspended sediment samples

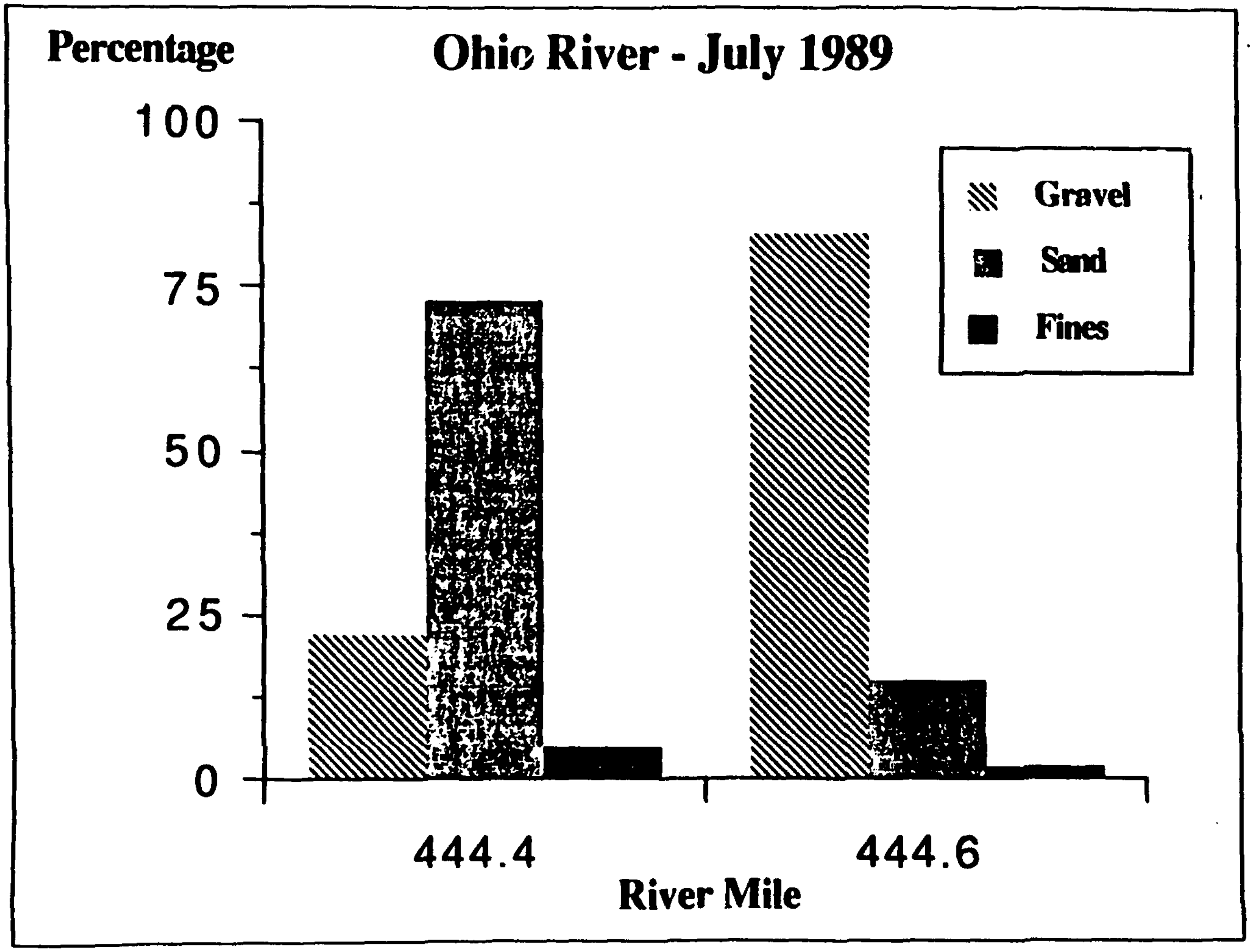


Figure 4. Percentages of gravel, sand, and fines (silt and clay sized particles) from two sites on the Ohio River, July 1989

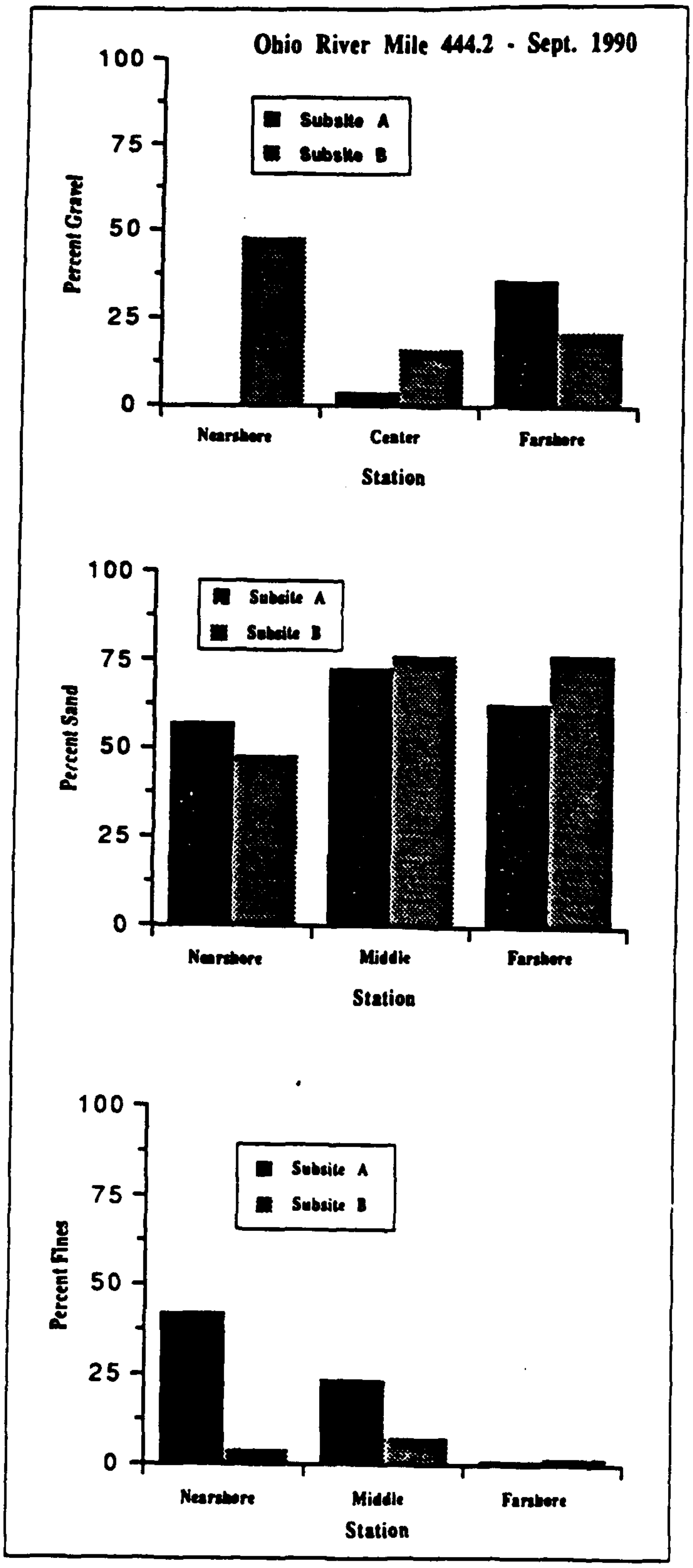
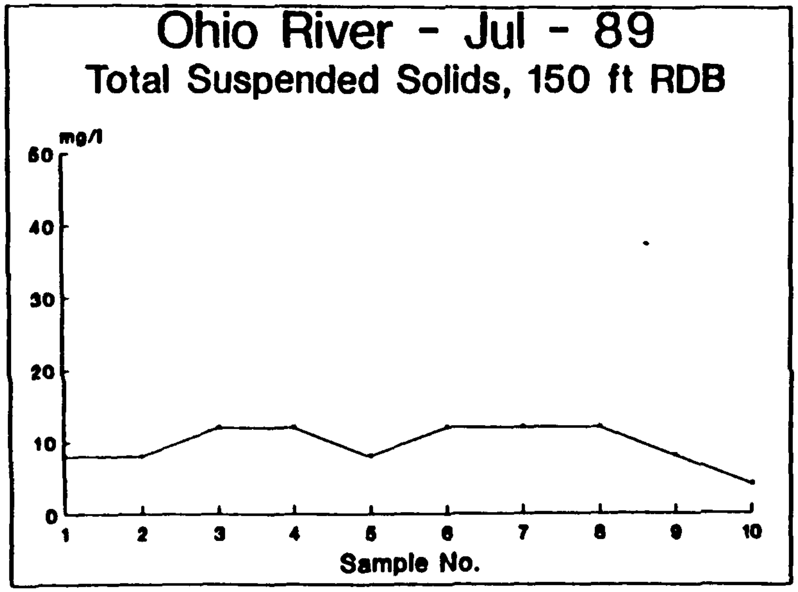
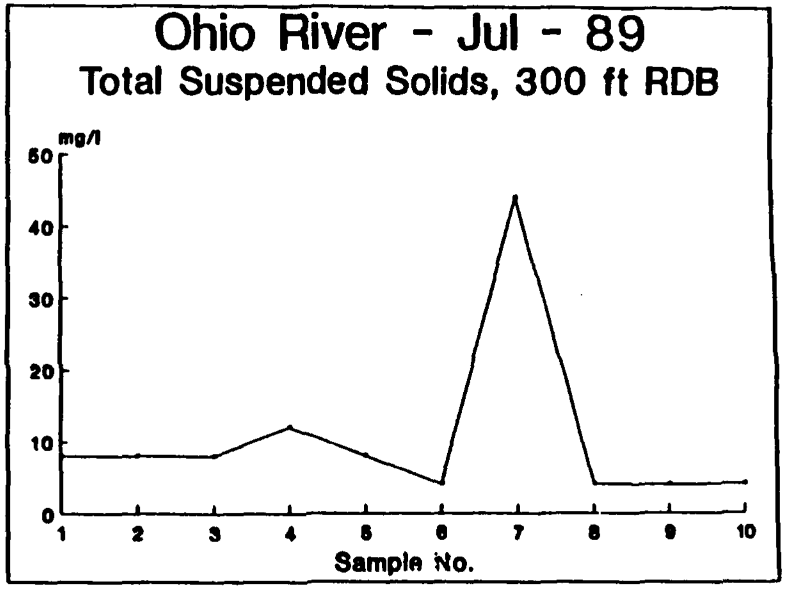


Figure 5. Percentages of gravel, sand, and fines at nearshore (100 ft), center (200 ft), and farshore (350 ft) portion of the mussel bed in the Ohio River

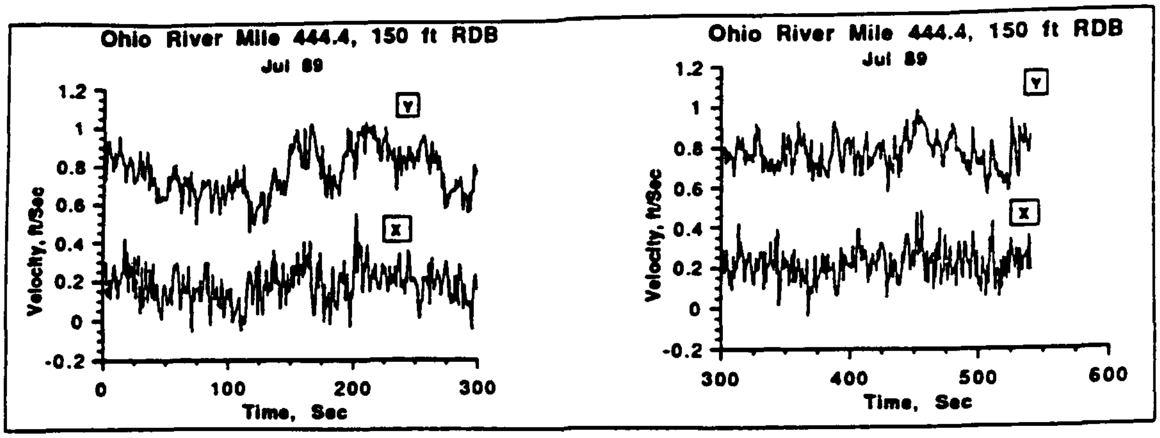


a. Location 150 ft from RDB

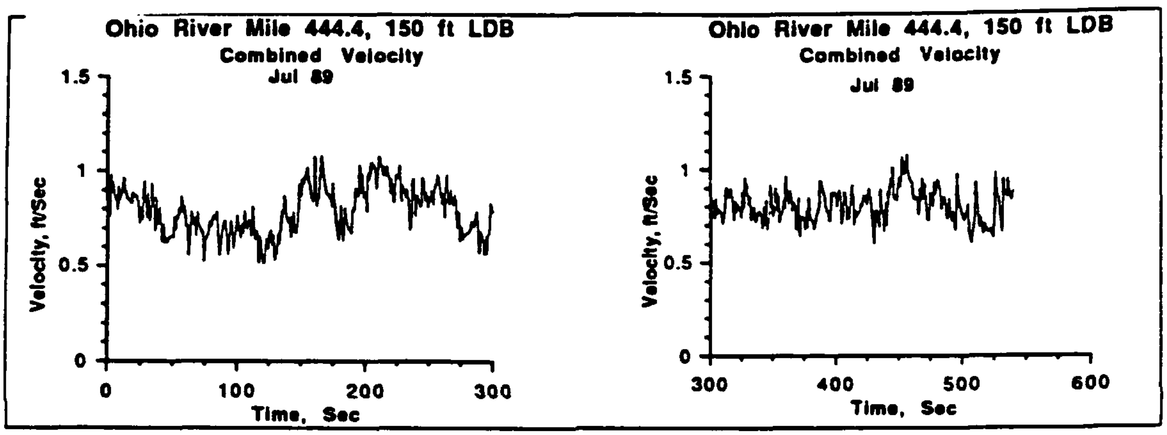


b. Location 300 ft from RDB

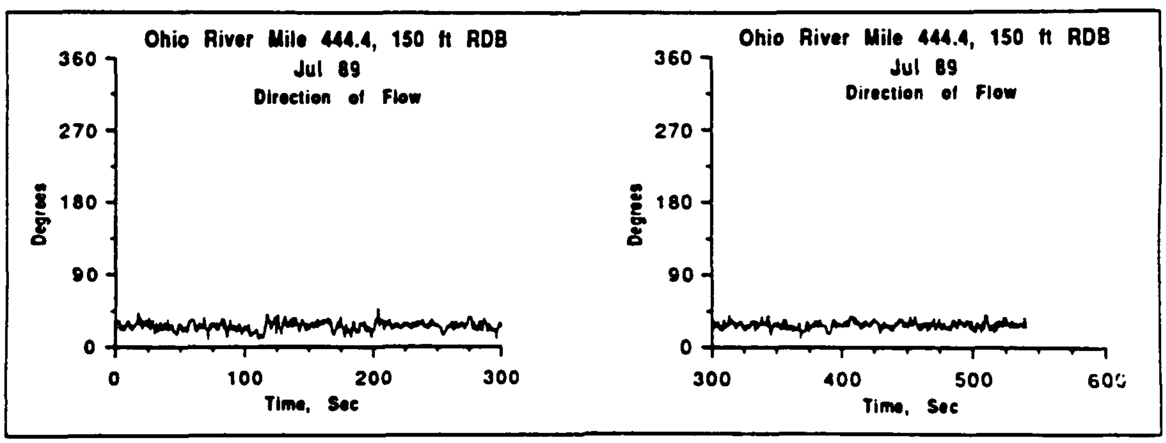
Figure 6. Suspended solids data collected at RM 444.4, Ohio River



a. Water velocity parallel to flow (Y) and at right angles to flow (X)

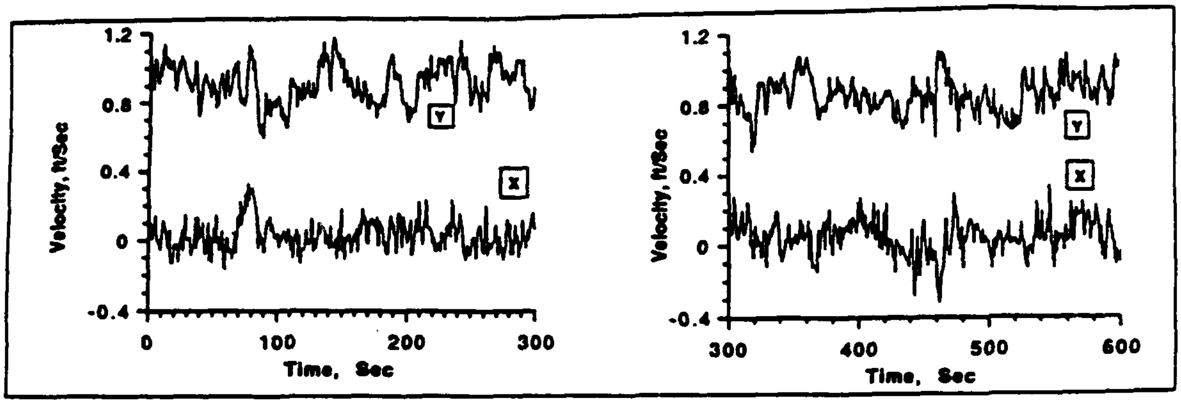


b. Combined magnitude of flow (considering Y and X)

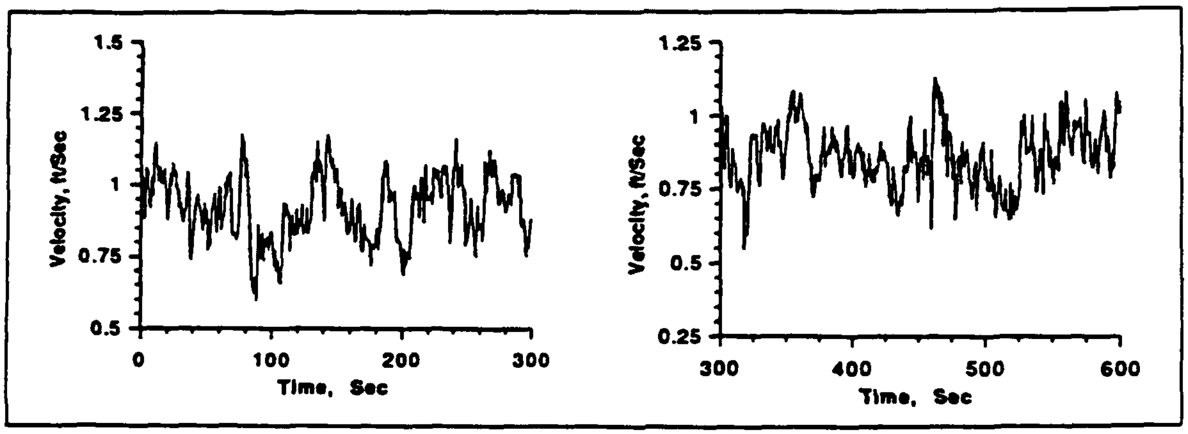


c. Compass readings showing direction of flow

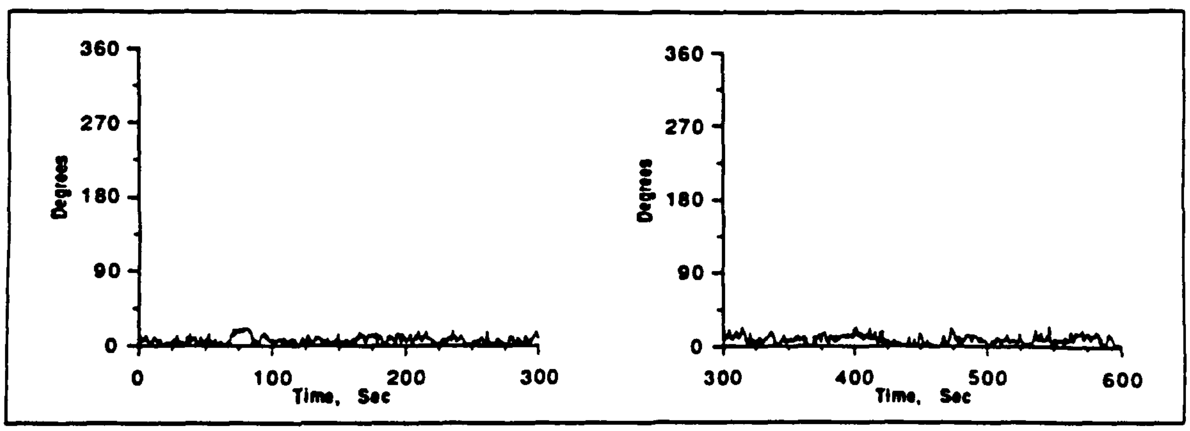
Figure 7. Continuous water velocity data 150 ft from the RDB, RM 444.4, Ohio River, July 1989



a. Water velocity parallel to now (Y) and at right angles to flow (X)



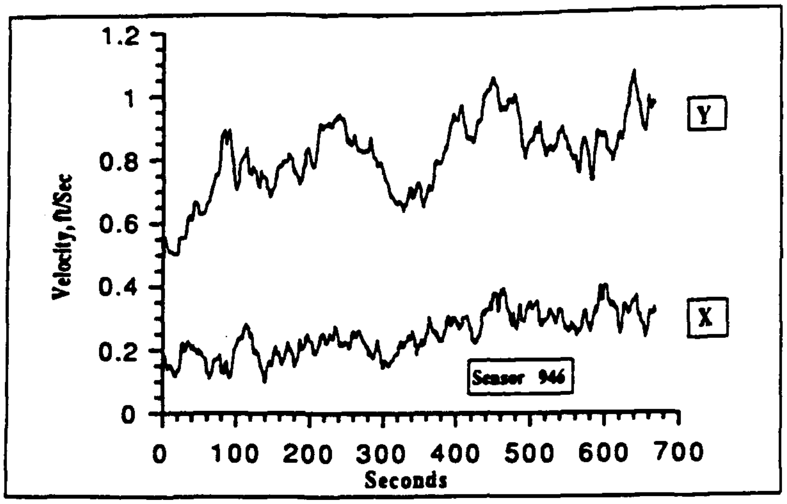
b. Combined magnitude of flow (considering Y and X)

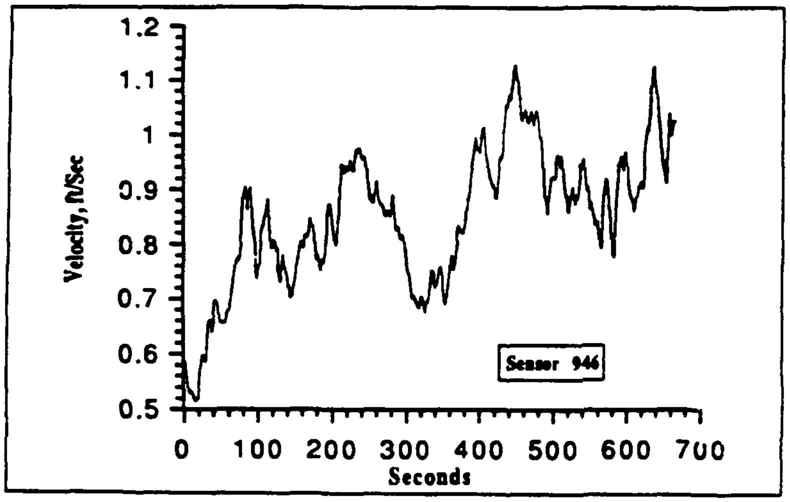


c. Compass readings showing direction of flow

Figure 8. Continuous water velocity data 300 ft from the RDB, RM 444.4, Ohio River, July 1989

a. Water velocity parellel to flow (Y) and at right angles to flow (X)





b. Combined magnitude of flow (considering Y and X)

c. Compass readings showing direction of flow

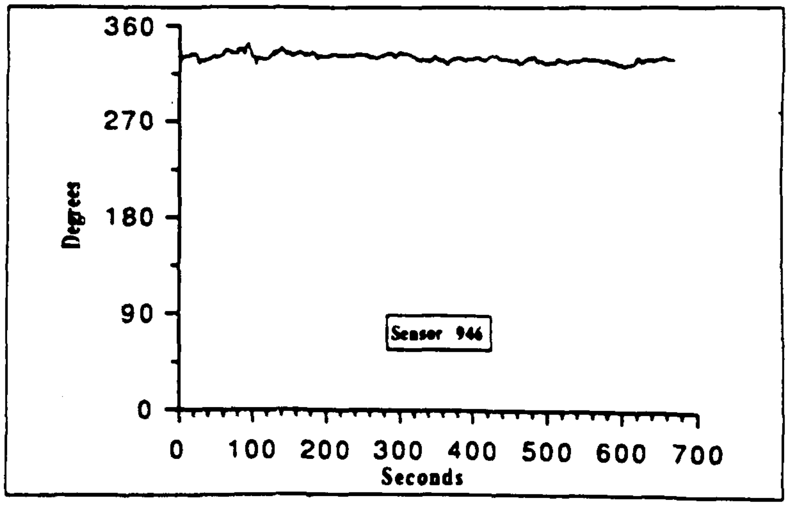
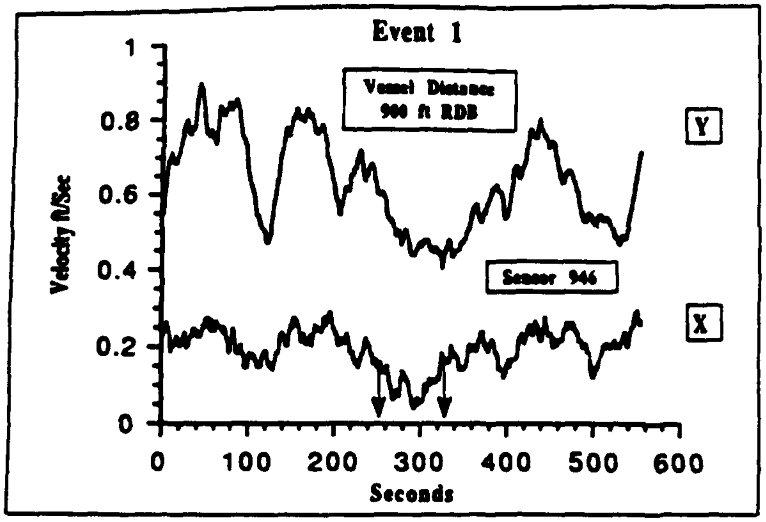
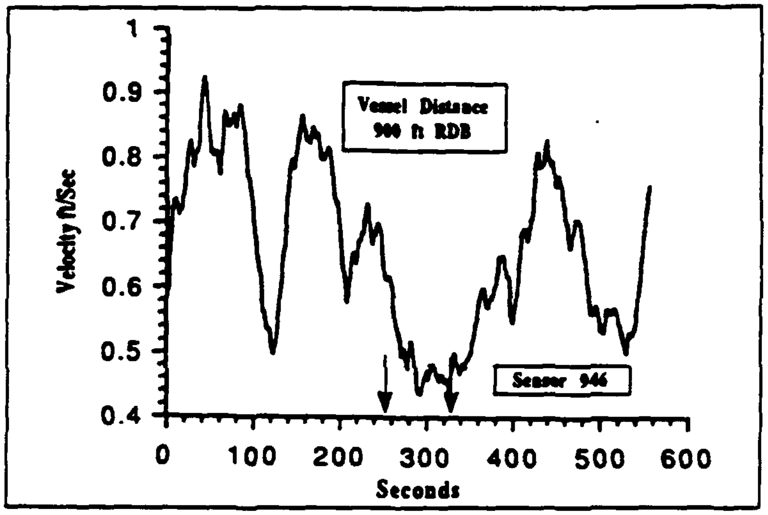


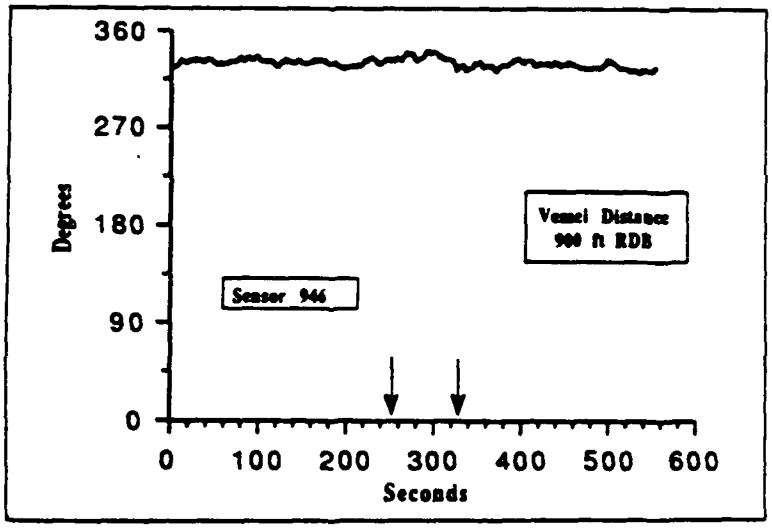
Figure 9. Continuous water velocity data 100 ft from RDB, ambient conditions, RM 444.4, Ohio River, September 1990



a. Water velocity parallel to flow (Y) and at right angles to flow (X)



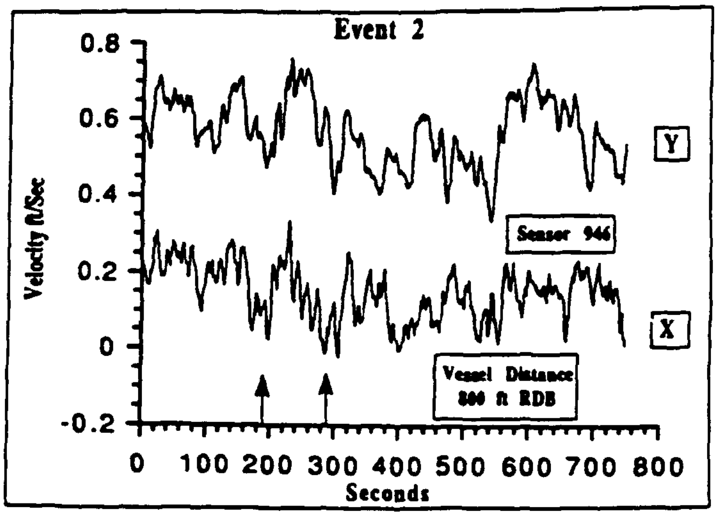
b. Combined magnitude of flow (considering Y and X)

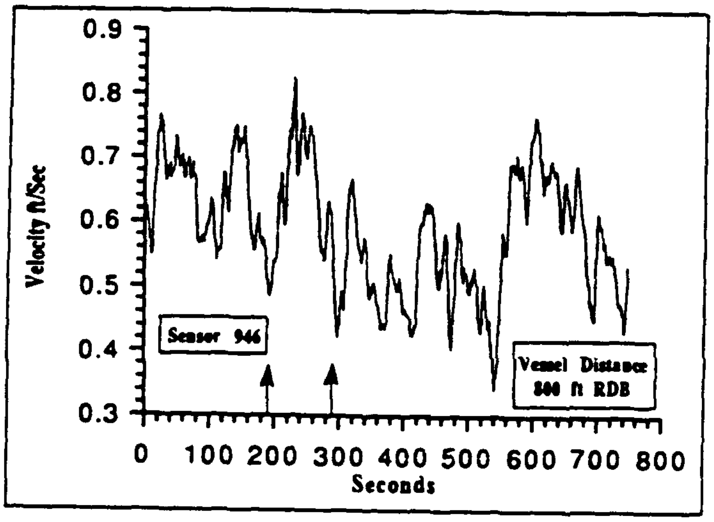


c. Compass readings showing direction of flow

Figure 10. Continuous water velocity data 100 ft from RDB, as a commercial vessel passes downriver 900 ft from RDB, RM 444.4, Ohio River, September 1990

a. Water velocity parallel to flow (Y) and at right angles to flow (X)





b. Combined magnitude of flow (considering Y and X)

c. Compass readings showing direction of flow

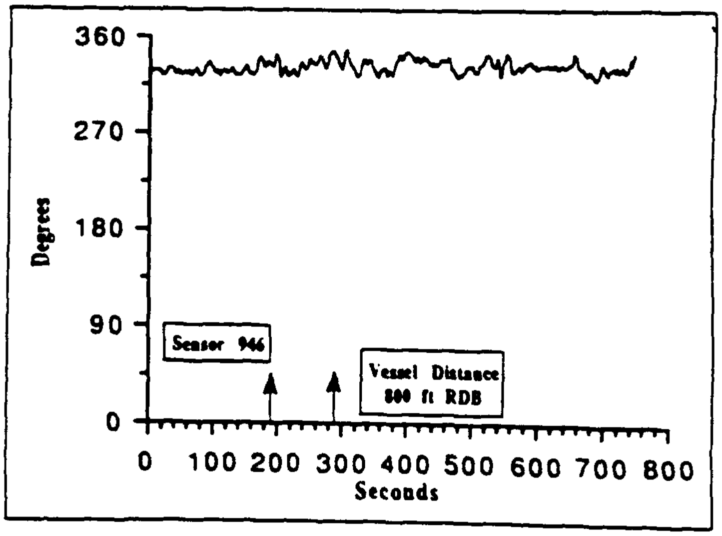
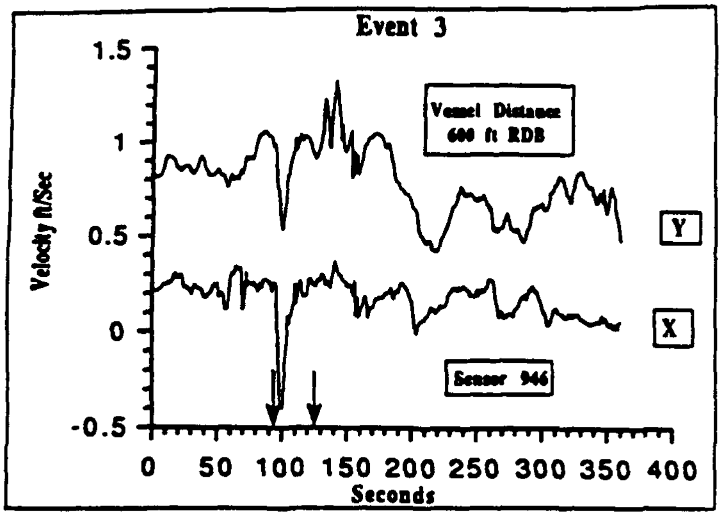
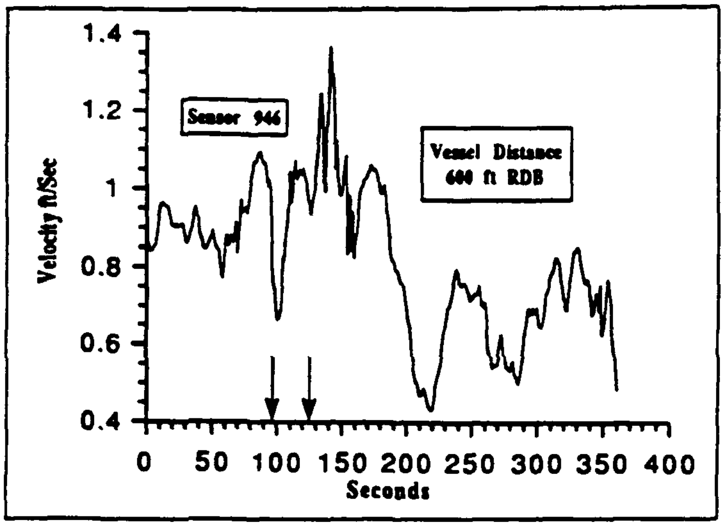


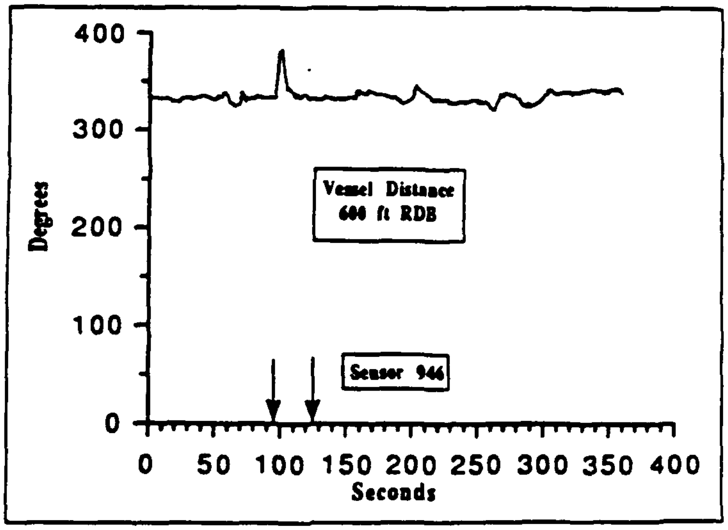
Figure 11. Continuous water velocity data 100 ft from RDB, as a commercial vessel passes upriver 800 ft from RDB, RM 444.4, Ohio River, September 1990



a. Water velocity parallel to flow (Y) and at right angles to flow (X)

b. Combined magnitude of flow (considering Y and X)

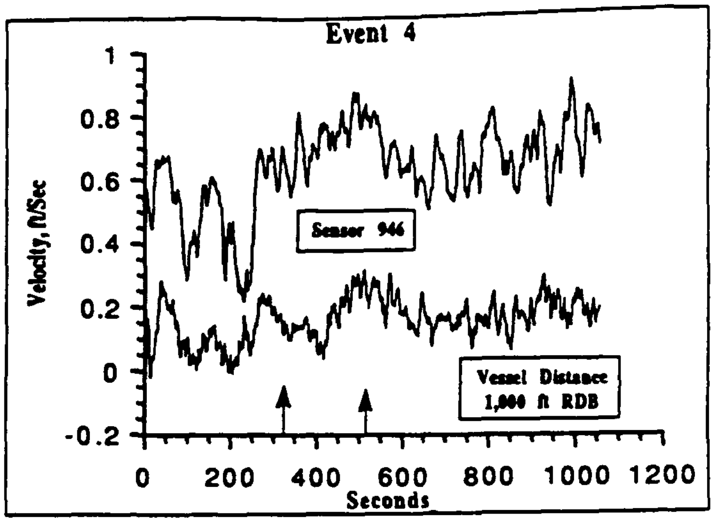


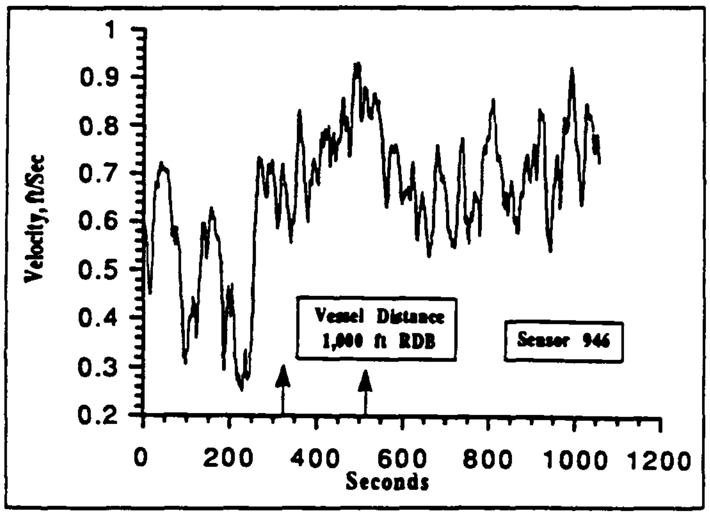


c. Compass readings showing direction of flow

Figure 12. Continuous water velocity data 100 ft from RDB, as a commercial vessel passes downriver 600 ft from RDB, RM 444.4, Ohio River, September 1990

a. Water velocity parallel to flow (Y) and at right angles to flow (X)





b. Combined magnitude of flow (considering Y and X)

c. Compass readings showing direction of flow

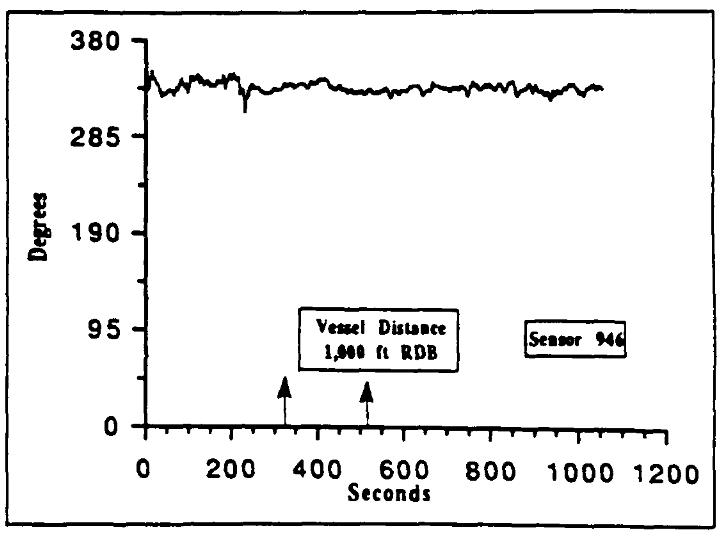


Figure 13. Continuous water velocity data 100 ft from RDB, RM 444.4, Ohio River, September 1990

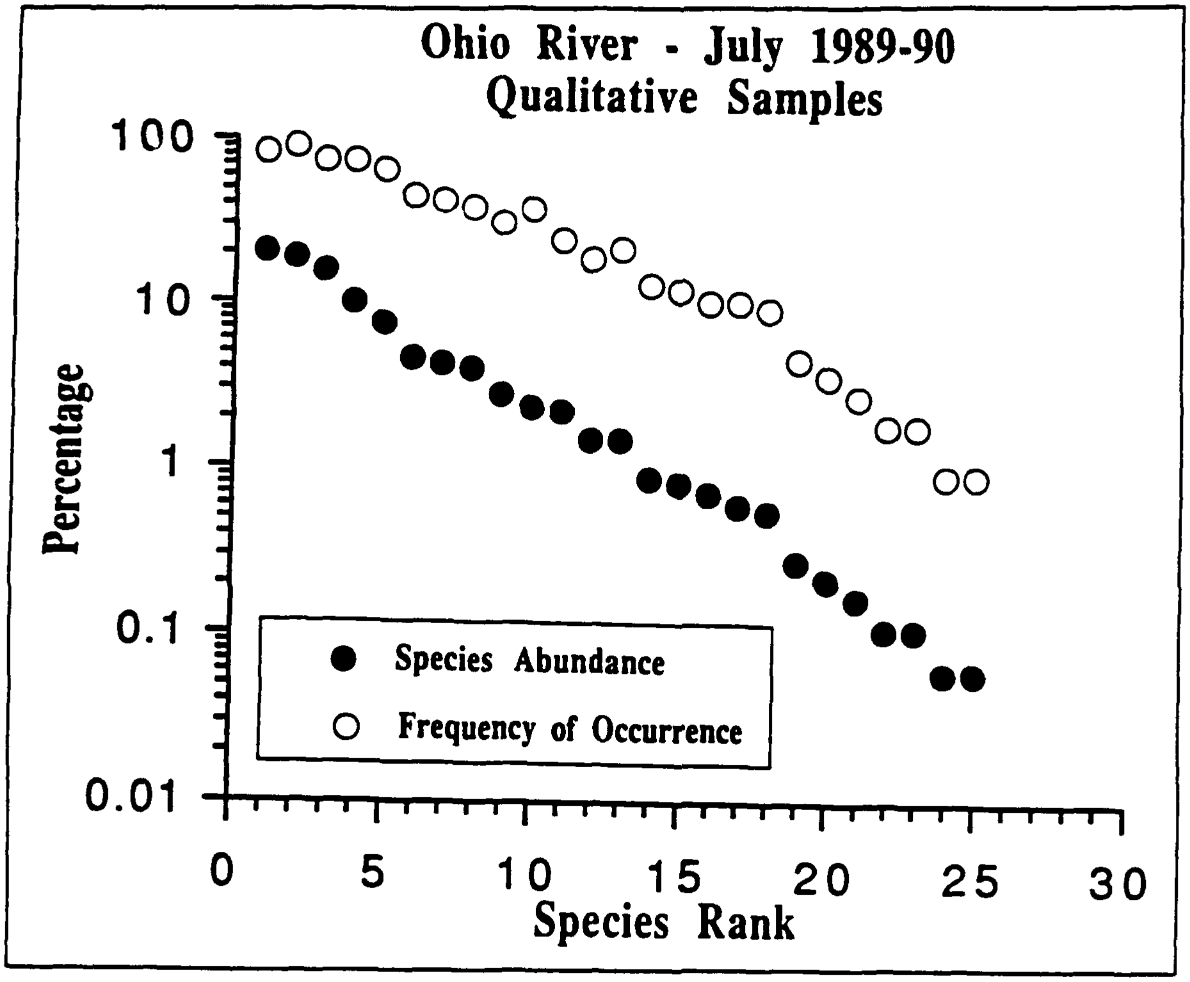
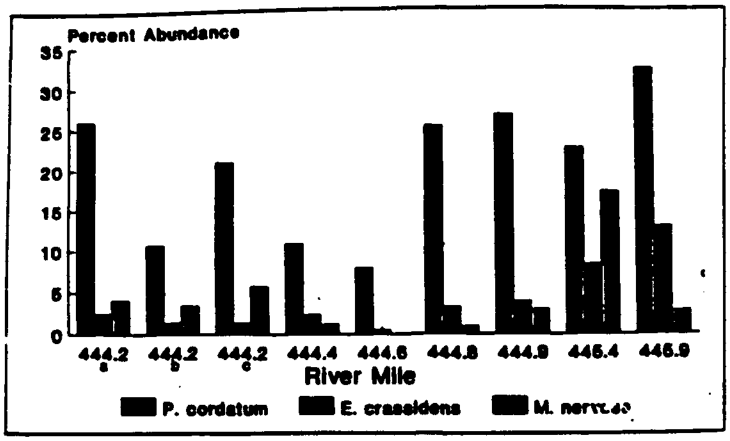
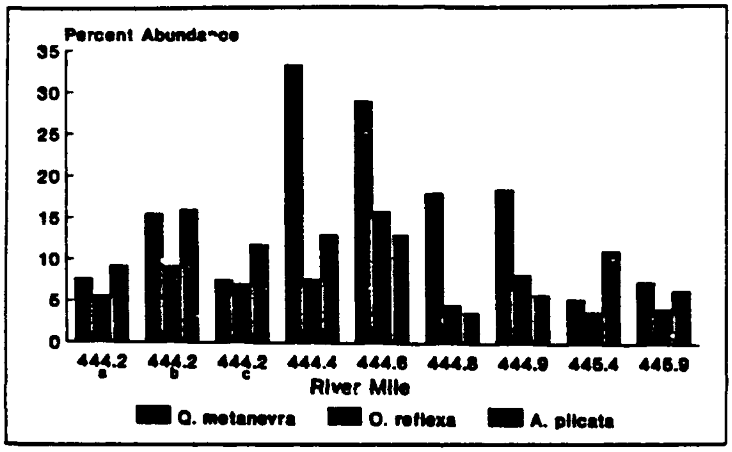


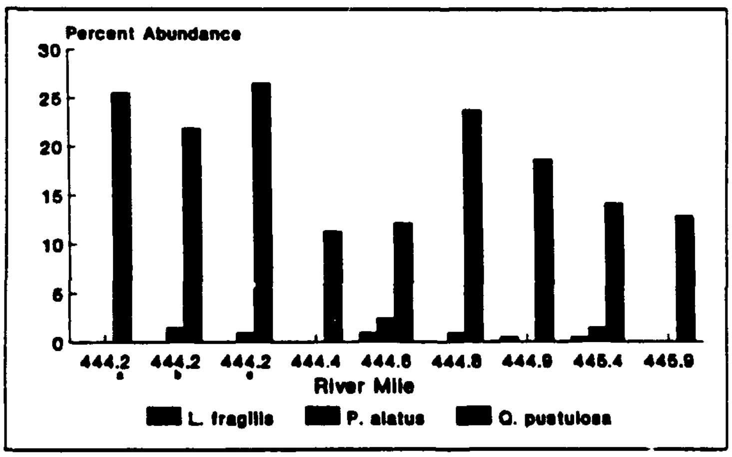
Figure 14. Species abundance and frequency of occurrence (percent) versus species rank for freshwater mussels collected using qualitative methods at the Ohio River, 1989-90



a. *P. cordatum, E. crassidens, M. nervosa*



b. *Q. metanevra, O. reflexa, A. plicata*



c. *L. fragilis, P. alatus, Q. pustulosa*

Figure 15. Percentage species abundance at nine locations (RM 444.2-RM 445.6), Ohio River, 1989-90

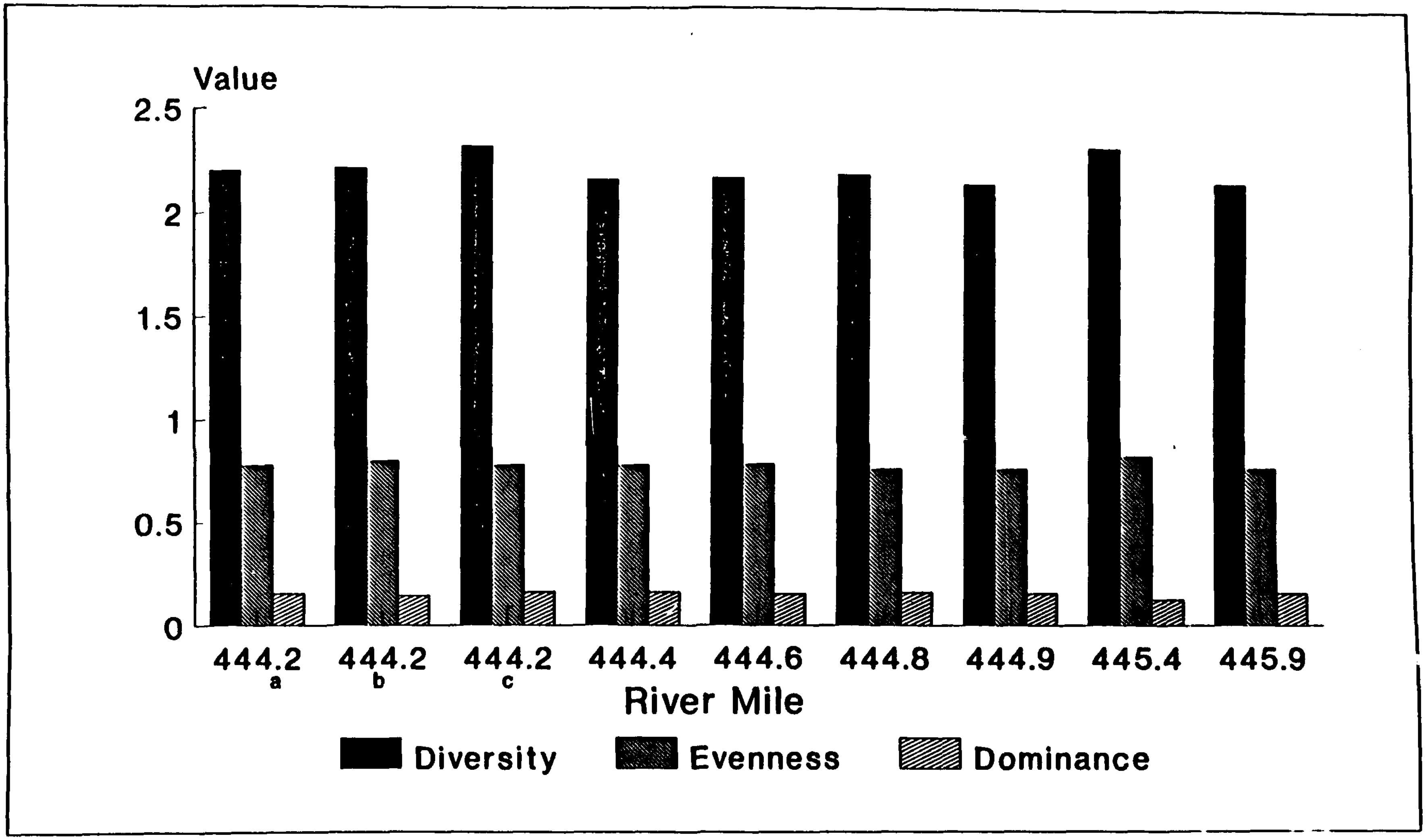
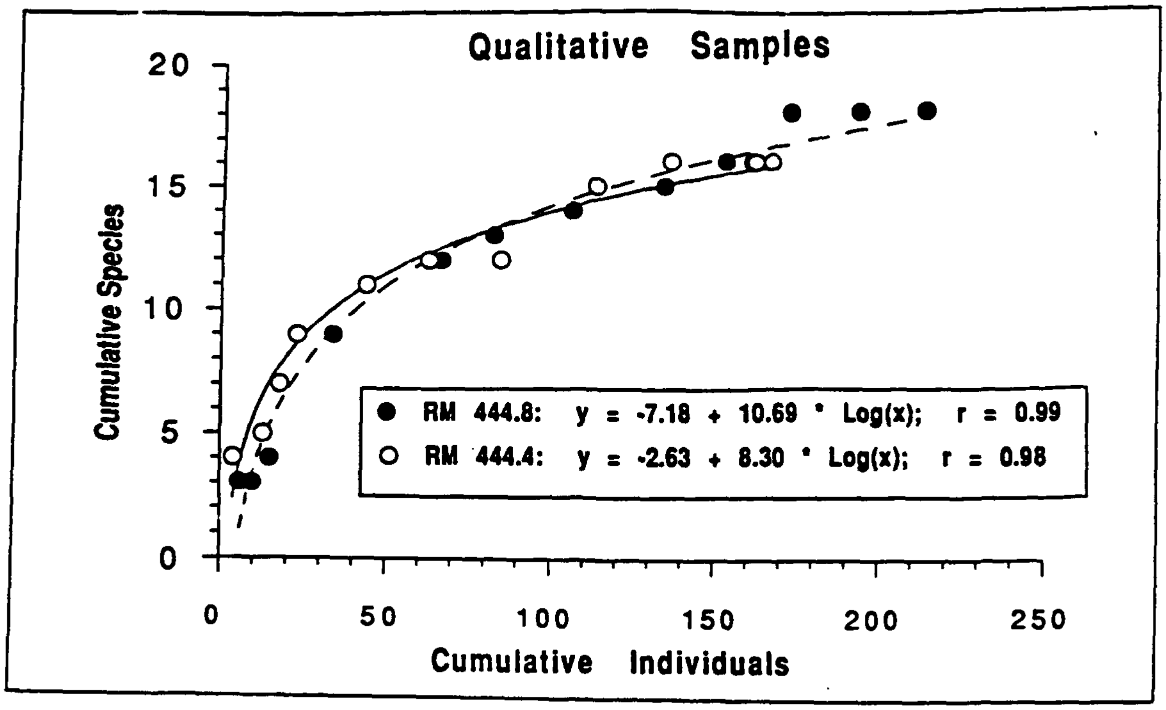
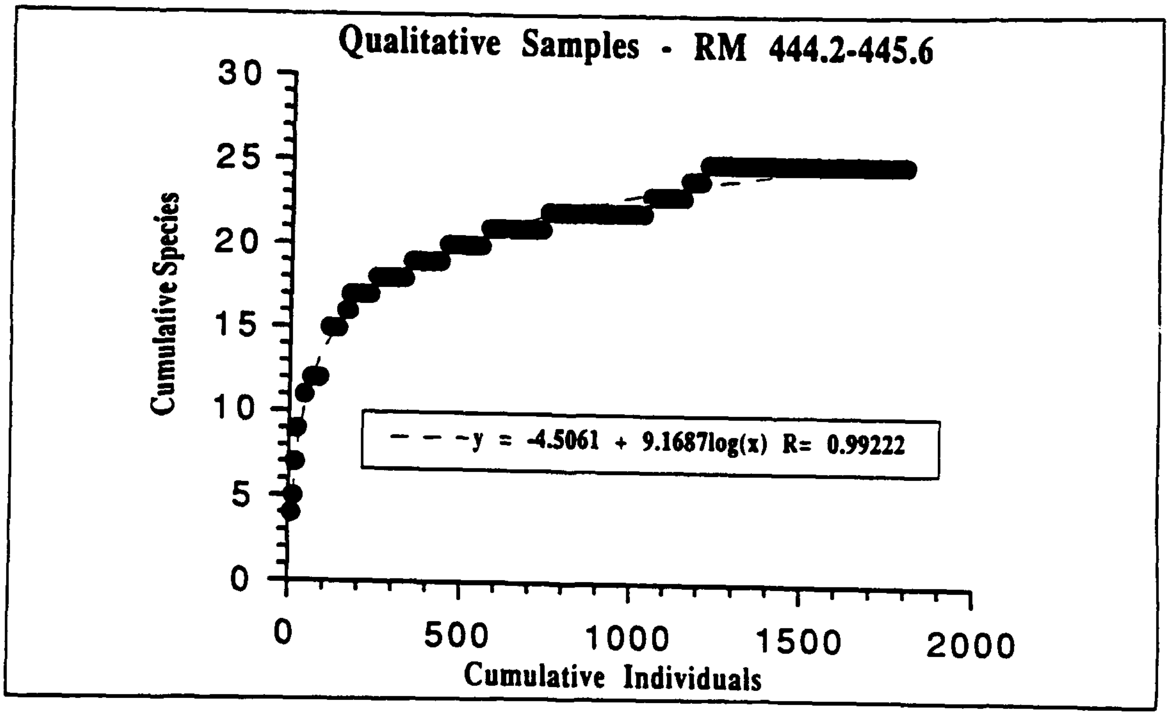


Figure 16. Evenness (J) and species diversity (H') for mussels collected using qualitative methods at six locations (RM 444.· - RM 444.6), Ohio River, July 1989

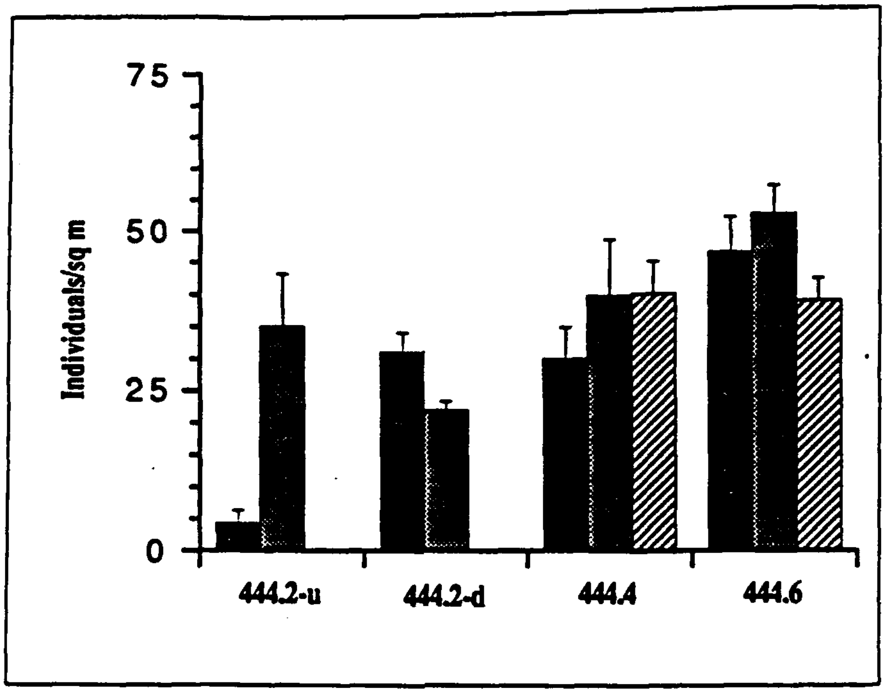


a. RM 444.8 and RM 444.4

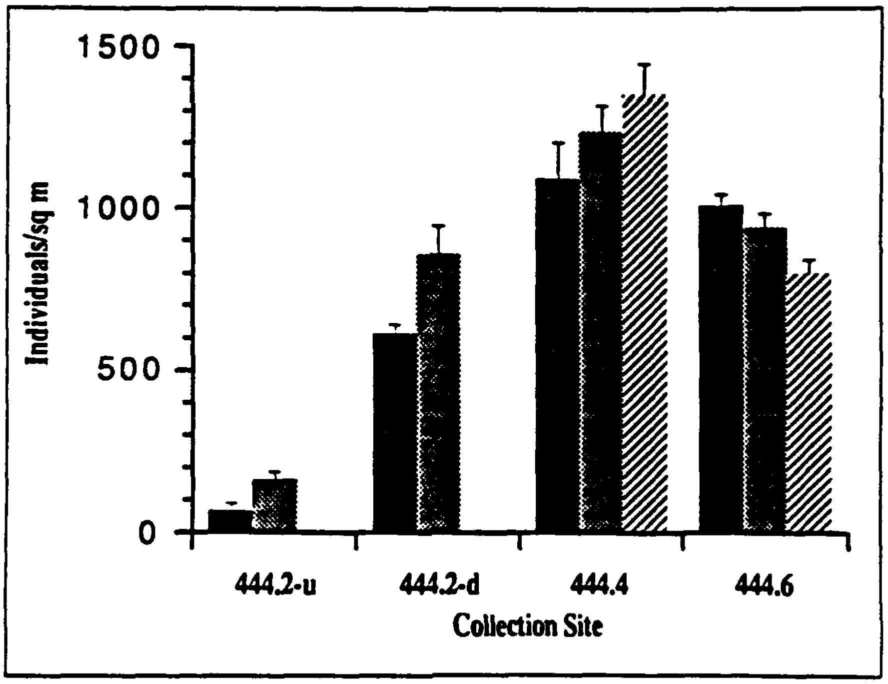


b. All nine sites combined

Figure 17. Cumulative species (Y) versus Log_{10} cumulative individuals for qualitative mussel collections

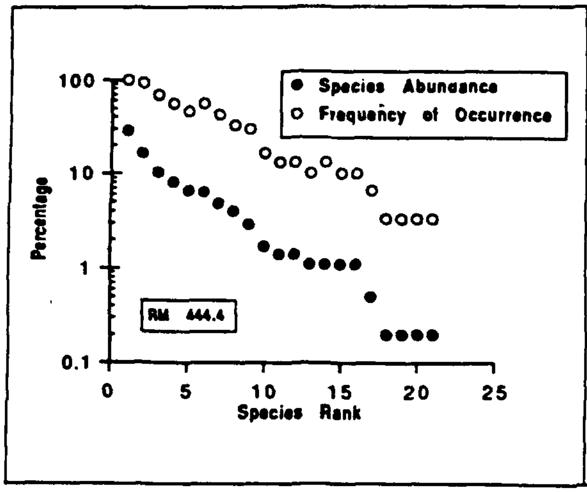


a. Unionids

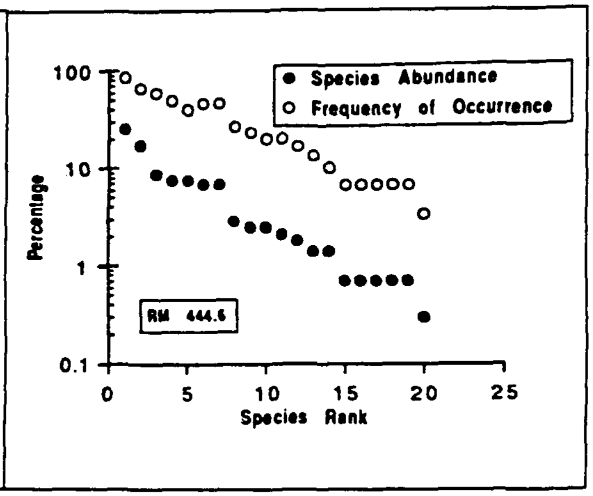


b. *C. fluminea*

Figure 18. Total density of unionids and *C. fluminea* collected in the Ohio River, 1989-90



a. RM 444.4



b. RM 444.6

Figure 19. Relationship between percentage abundance or frequency of occurrence (Y) and species rank (X) for quantitative samples collected at RM 444.4 and RM 444.6

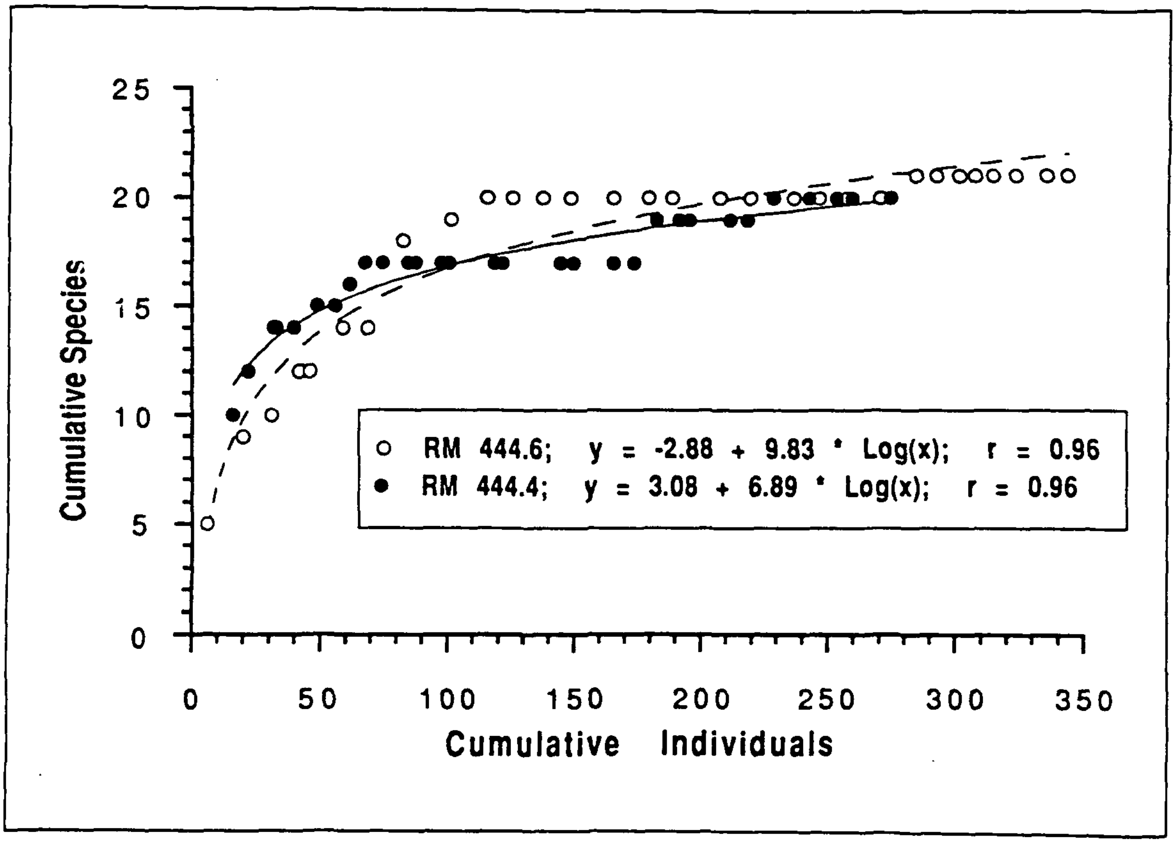
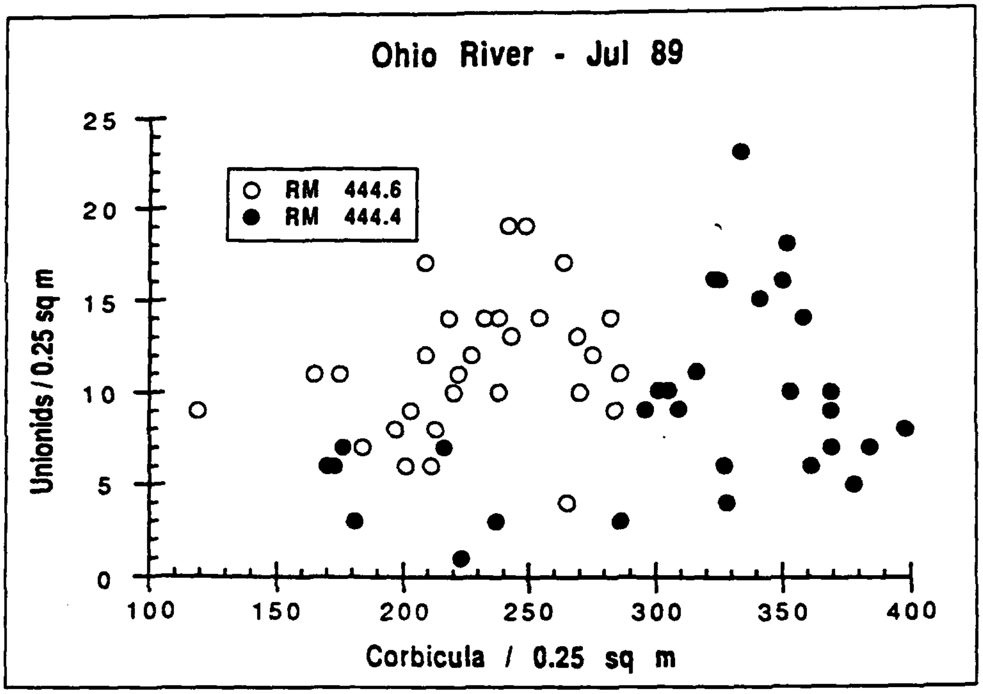
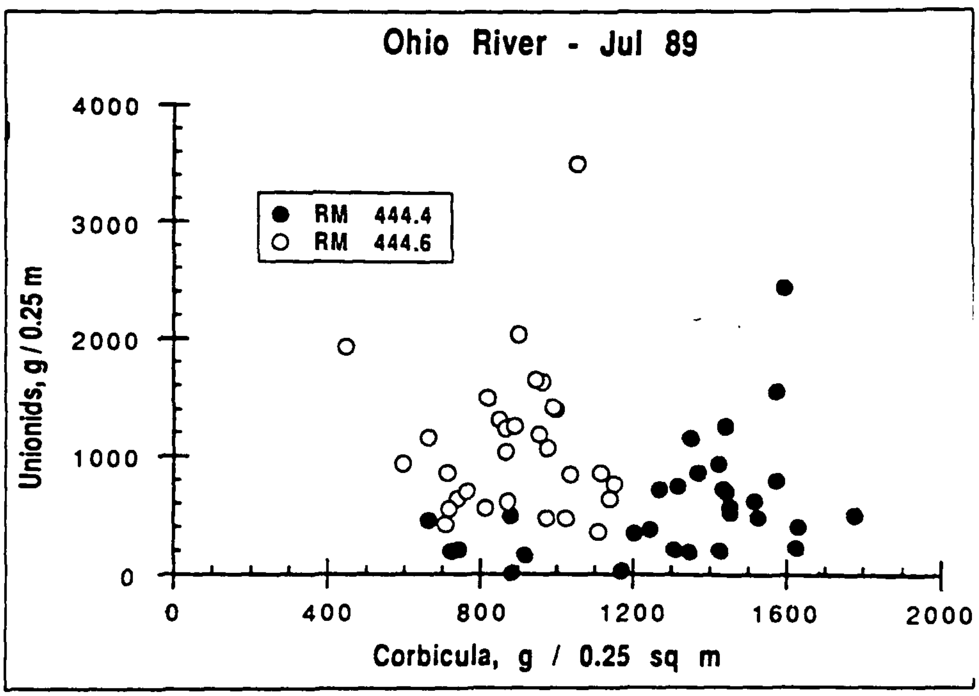


Figure 20. Cumulative species (Y) versus cumulative individuals for mussels collected using quantitative methods, July 1989, RM 444.4 and 444.6

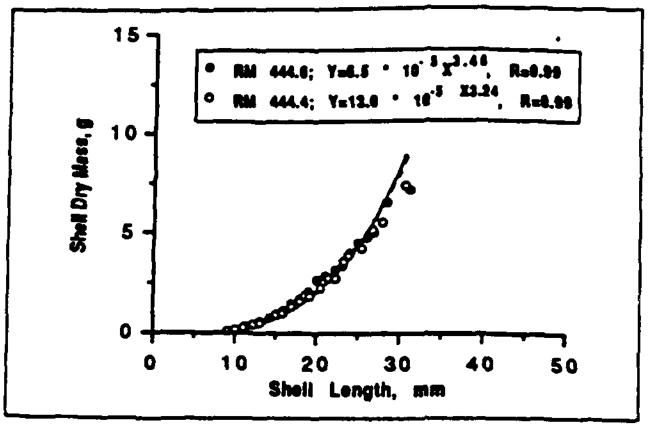


a. Density relationship

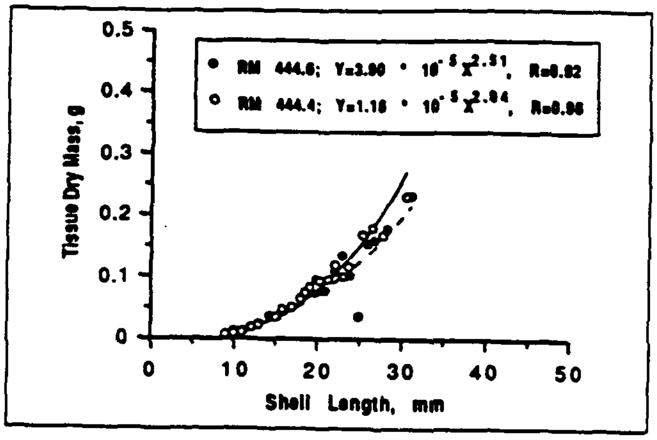


b. Biomass relationship

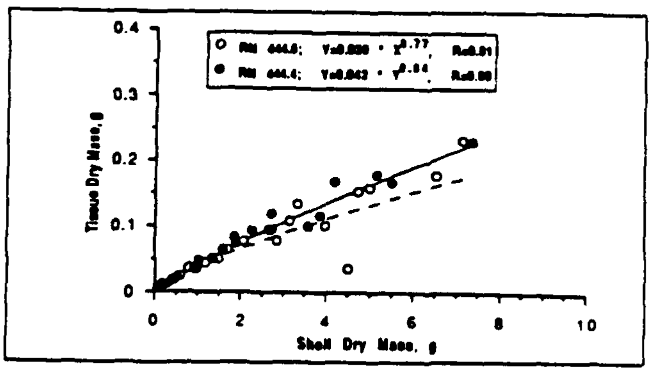
Figure 21. Relationship between unionids and *C. fluminea*



a. Relationship between shell dry mass (Y) and shell length (X)

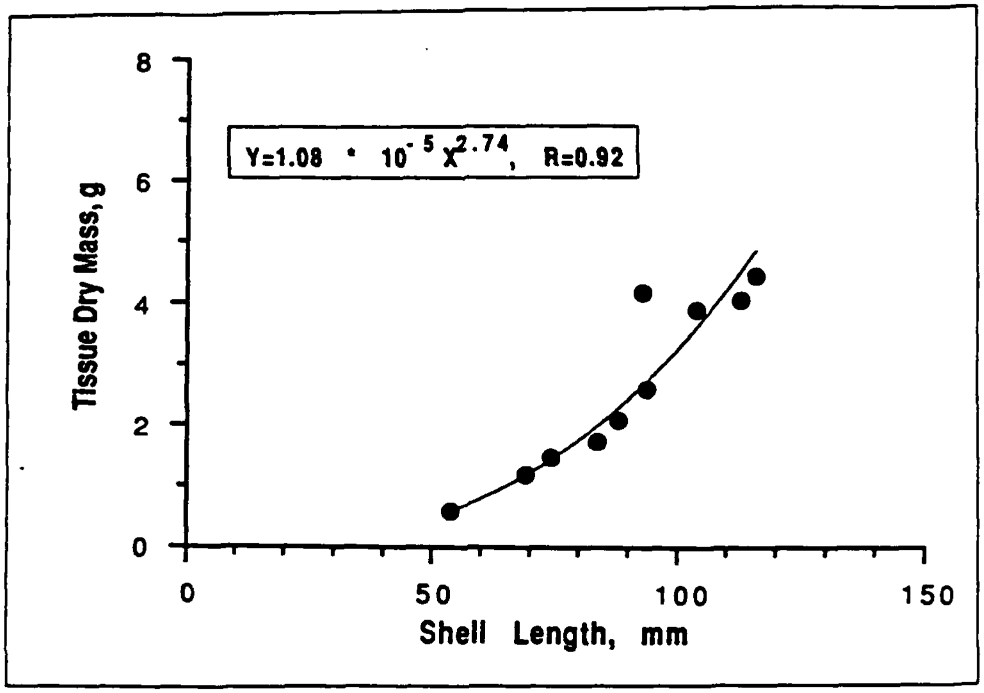


b. Relationship between tissue dry mass (Y) and shell length (X)

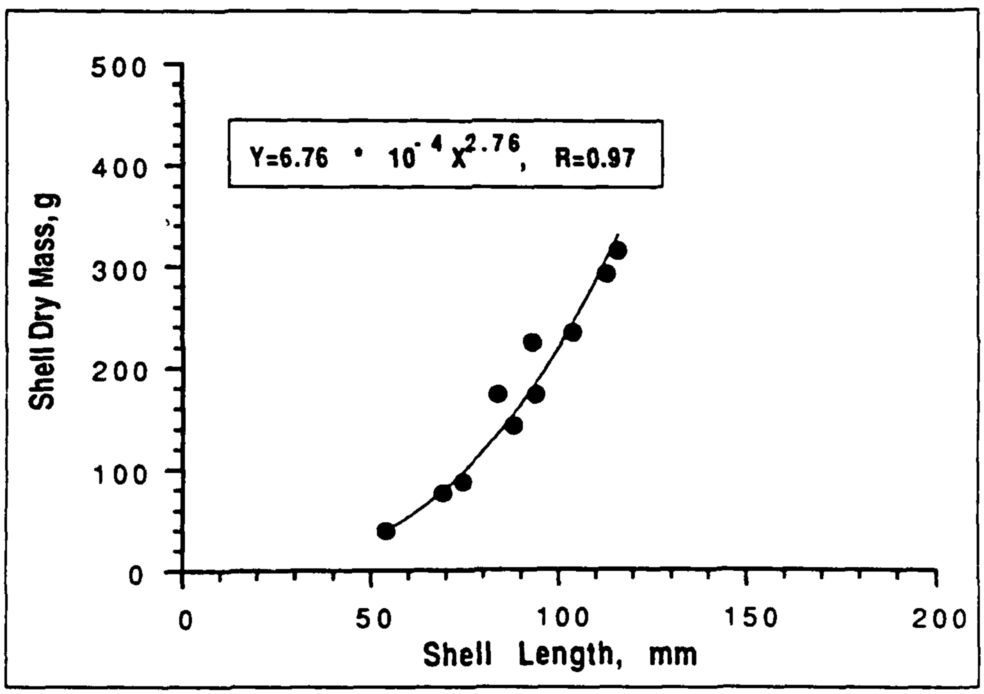


c. Relationship between tissue dry mass (Y) and shell dry mass (X)

Figure 22. Morphometric relationships for *C. fluminea*

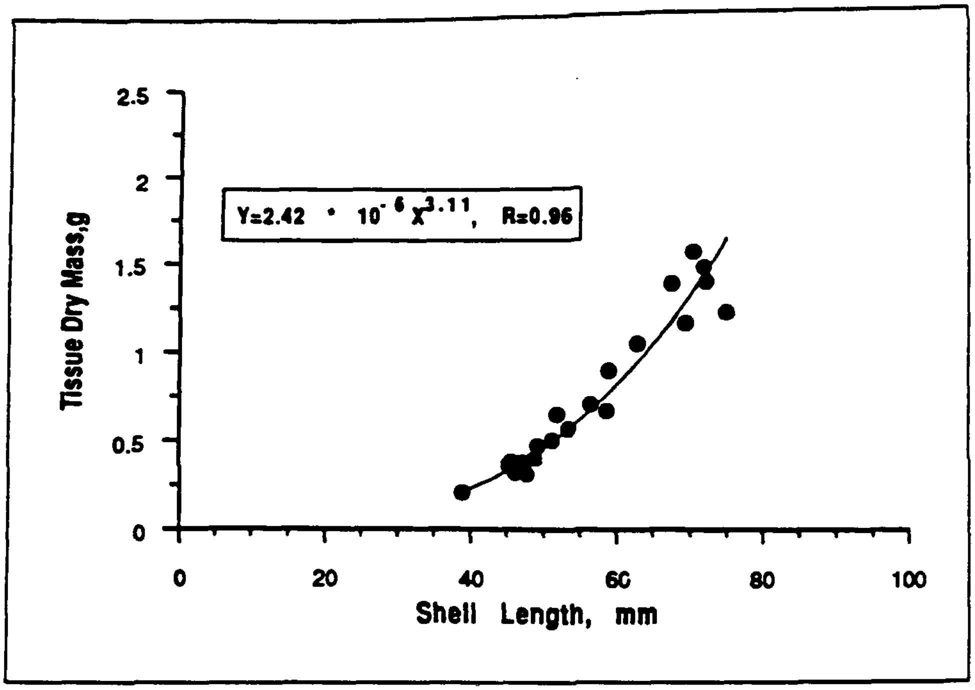


a. Relationship between tissue dry mass (Y) and shell length (X)

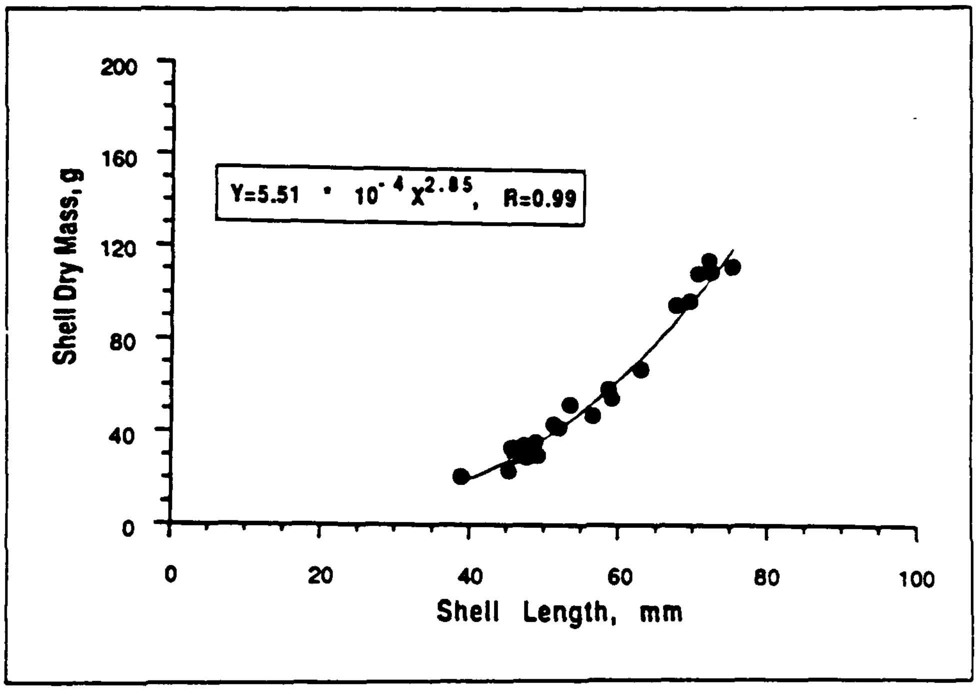


b. Relationship between shell dry mass (Y) and shell length (X)

Figure 23. Morphometric relationships for *A. plicata*

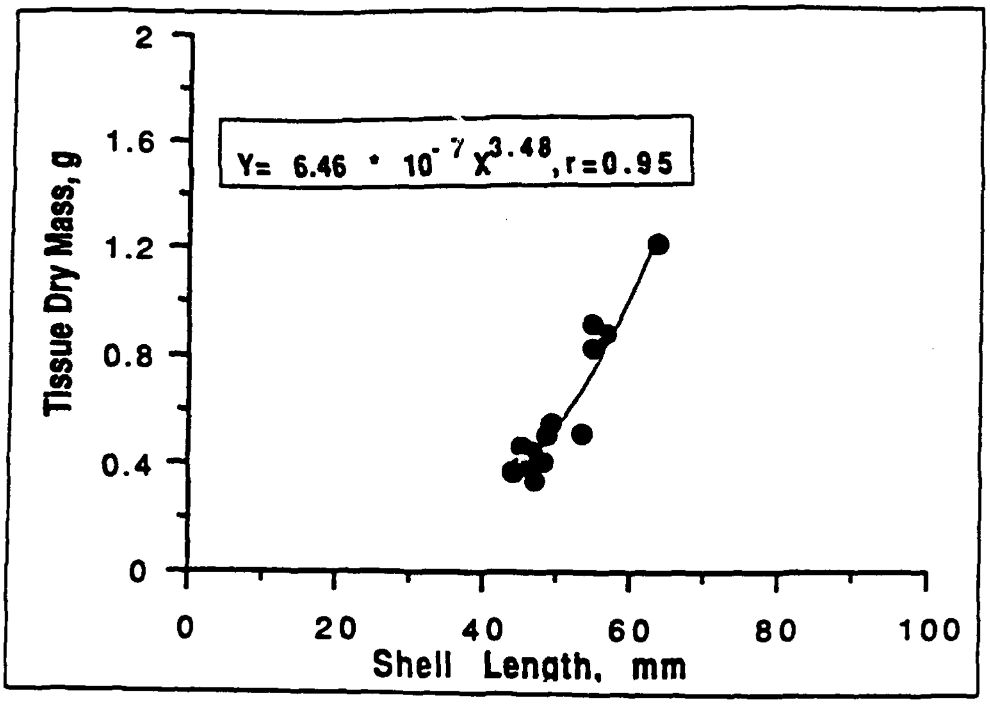


a. Relationship between tissue dry mass (Y) and shell length (X)

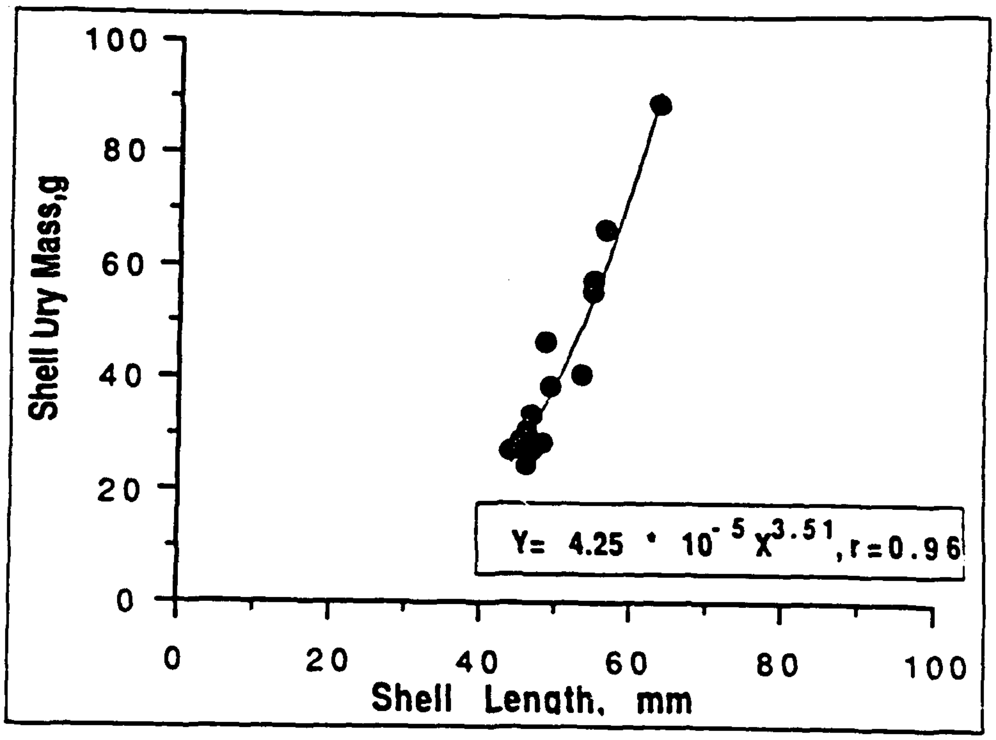


b. Relationship between shell dry mass (Y) and shell length (X)

Figure 24. Morphometric relationships for *Q. metanevra*

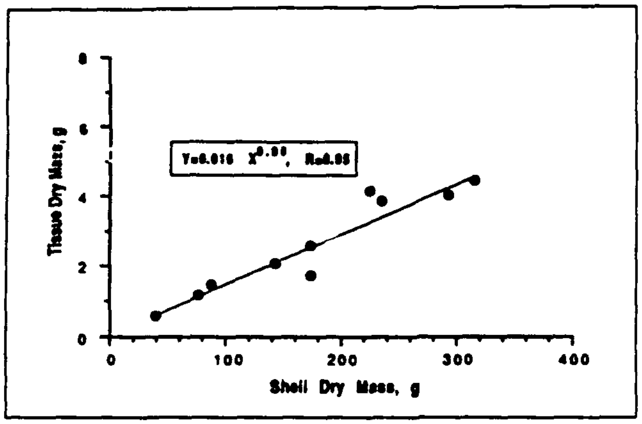


a. Relationship between tissue dry mass (Y) and shell length (X)

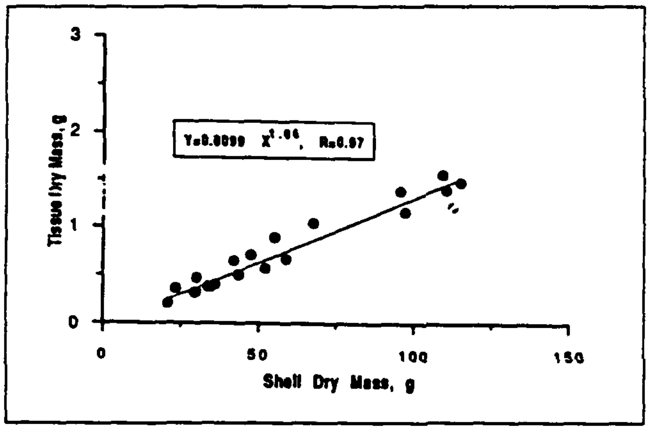


b. Relationship between shell dry mass (Y) and shell length (X)

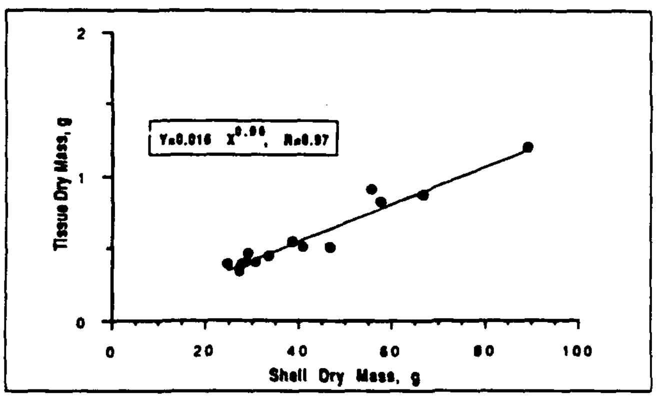
Figure 25. Morphometric relationships for *O. reflexa*



a. *Amblema plicata*

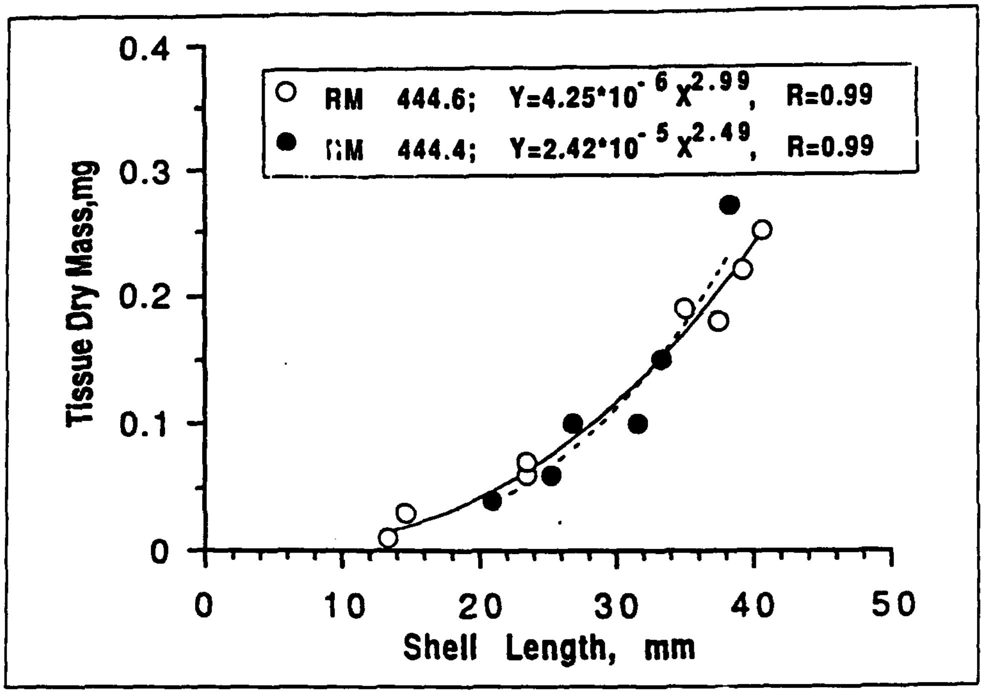


b. *Quadrula metanevra*

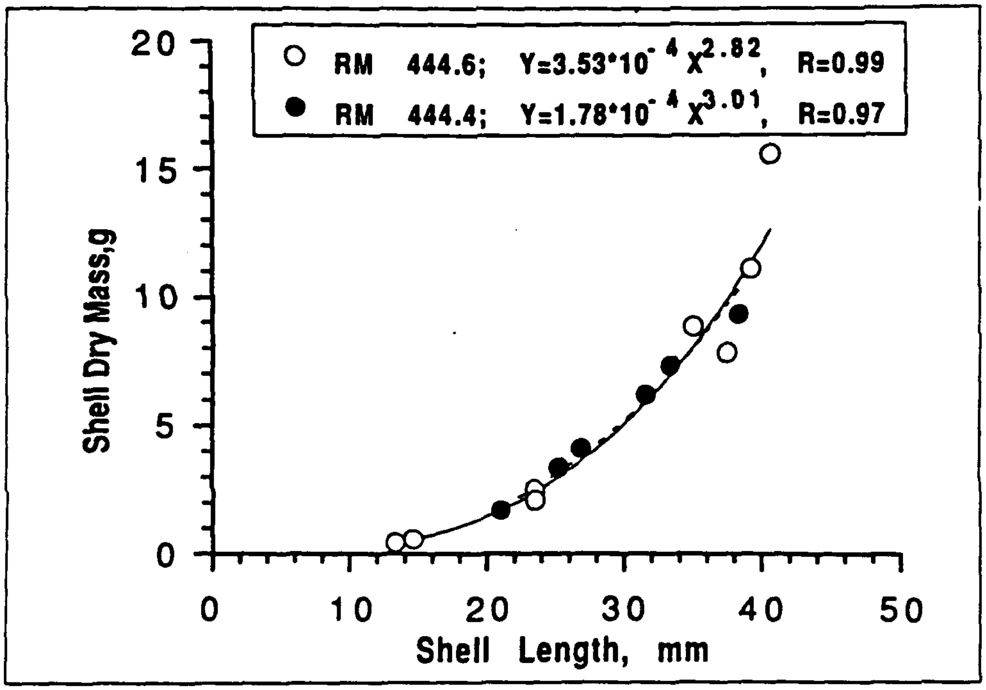


c. *Obliquaria reflexa*

Figure 26. Relationship between tissue dry.mass (Y) and shell dry mass (Y) for three species of unionids

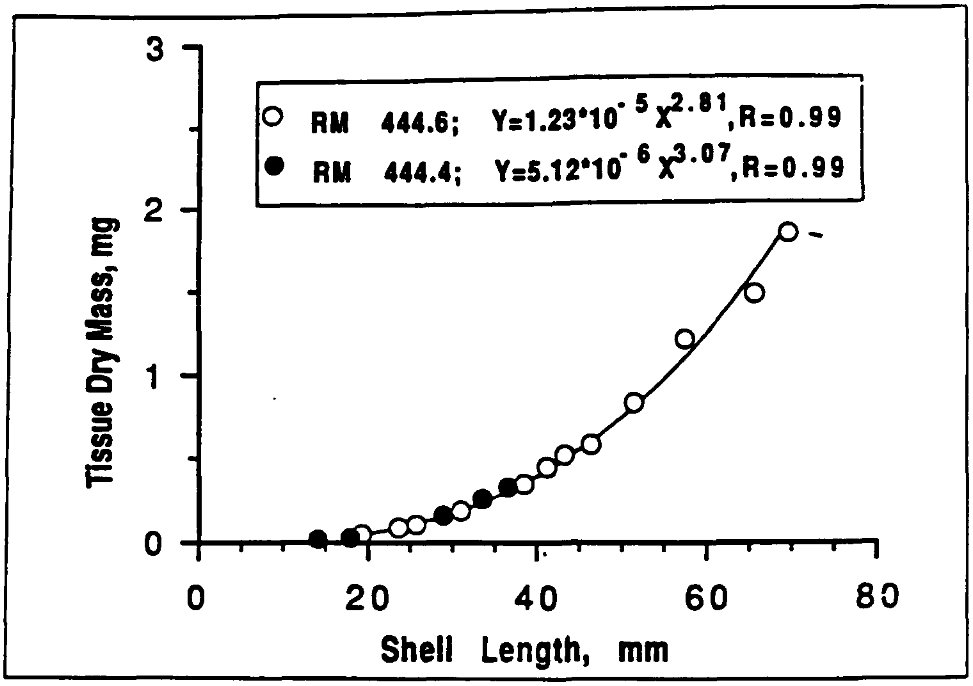


a. Relationship between tissue dry mass (Y) and shell length (X)

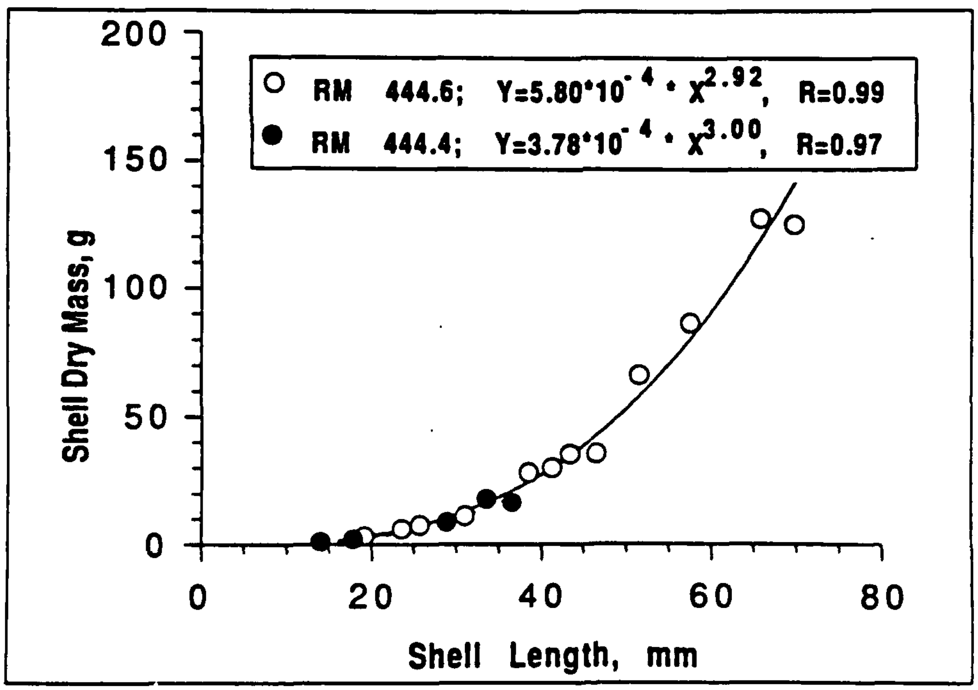


b. Relationship between shell dry mass (Y) and shell length (X)

Figure 27. Morphometric relationships for *T. truncata*

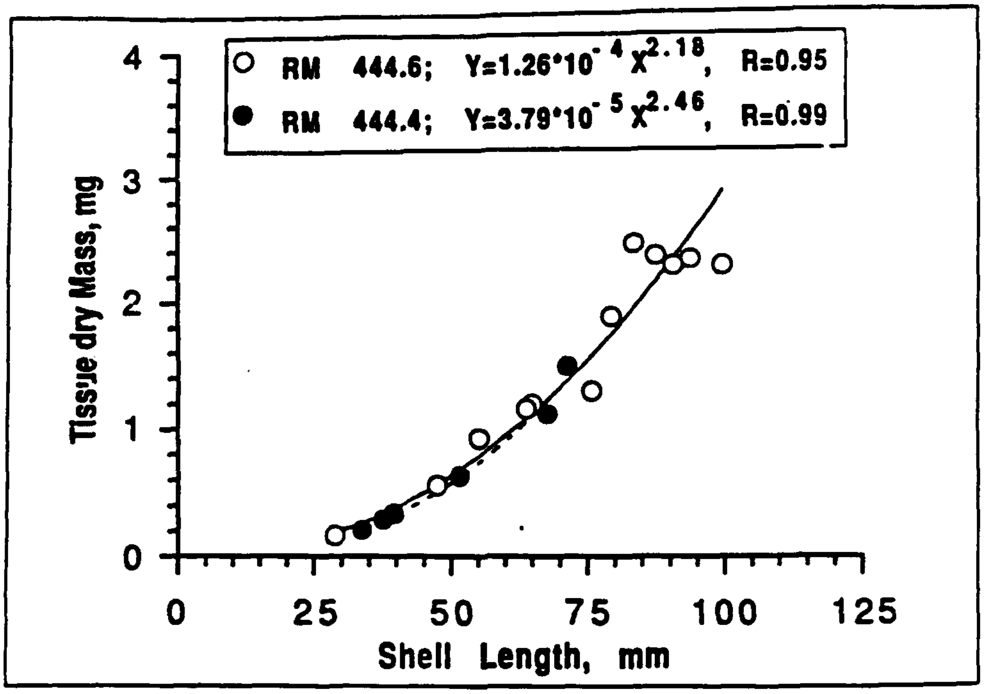


a. Relationship between tissue dry mass (Y) and shell length (X)

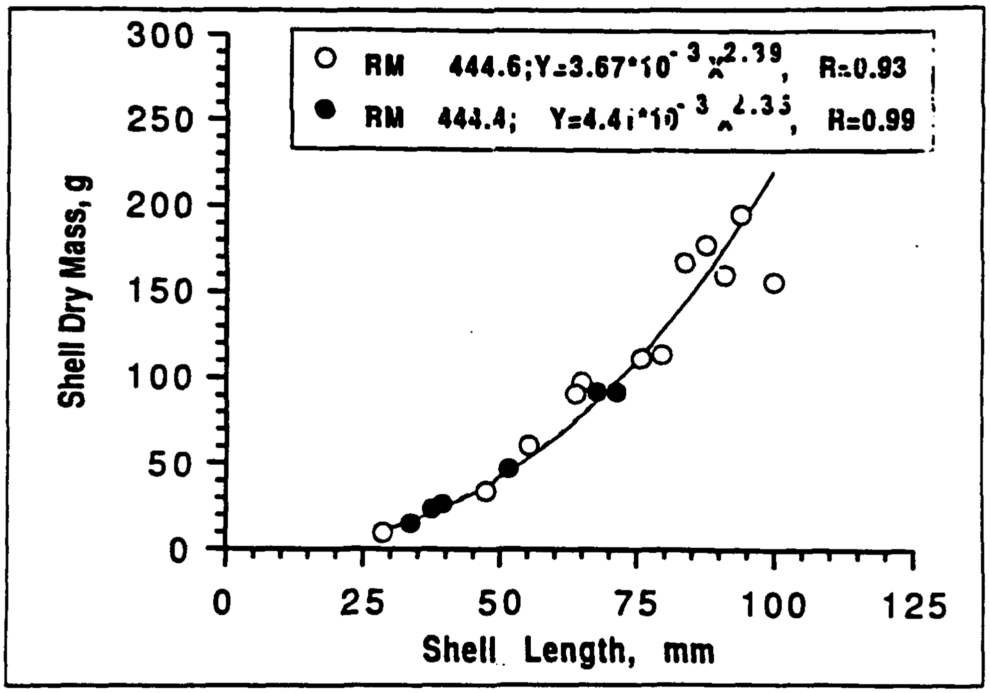


b. Relationship between shell dry mass (Y) and shell length (X)

Figure 28. Morphometric relationships for *Q. pustulosa*

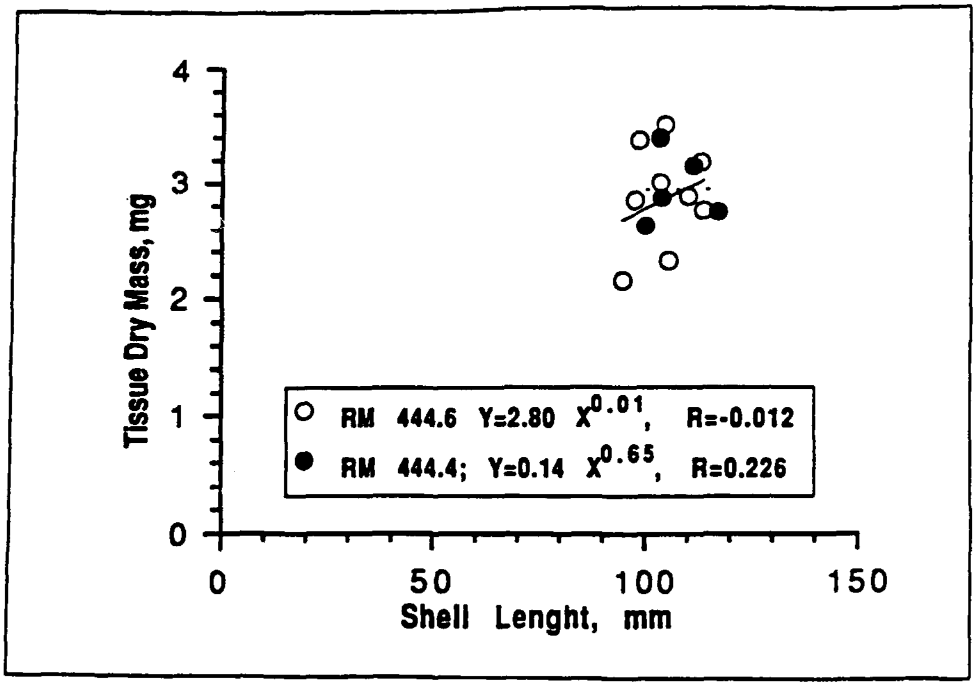


a. Relationship between tissue dry mass (Y) and shell length (X)

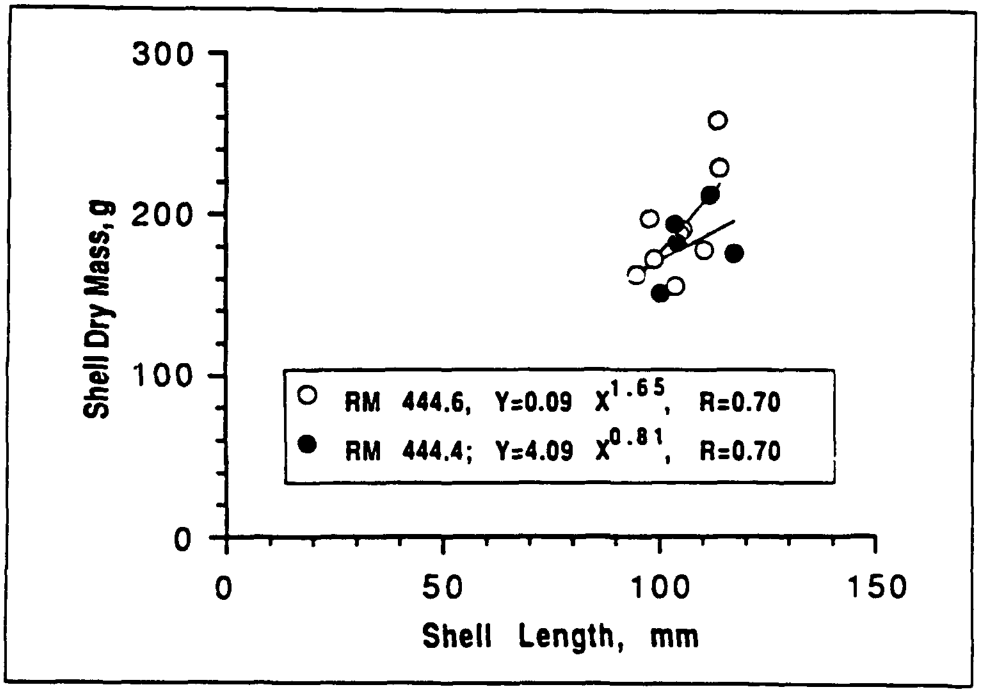


b. Relationship between shell dry mass (Y) and shell length (X)

Figure 29. Morphometric relationships for *P. cordatum*



a. Relationship between tissue dry mass (Y) and shell length (X)



b. Relationship between shell dry mass (Y) and shell length (X)

Figure 30. Morphometric relationships for *E. crassidens*

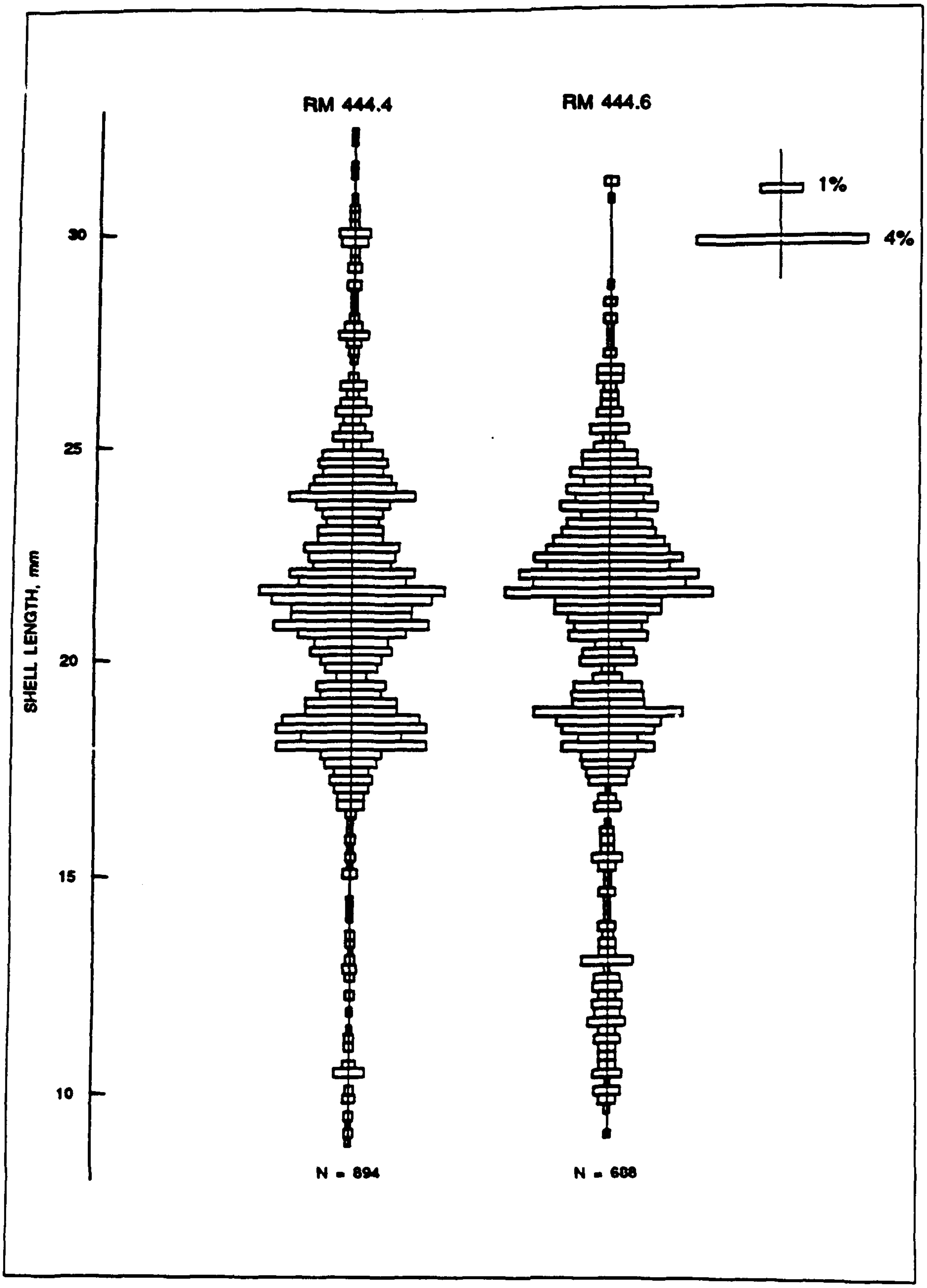


Figure 31. Length-frequency histograms for *C. fluminea*, 1989

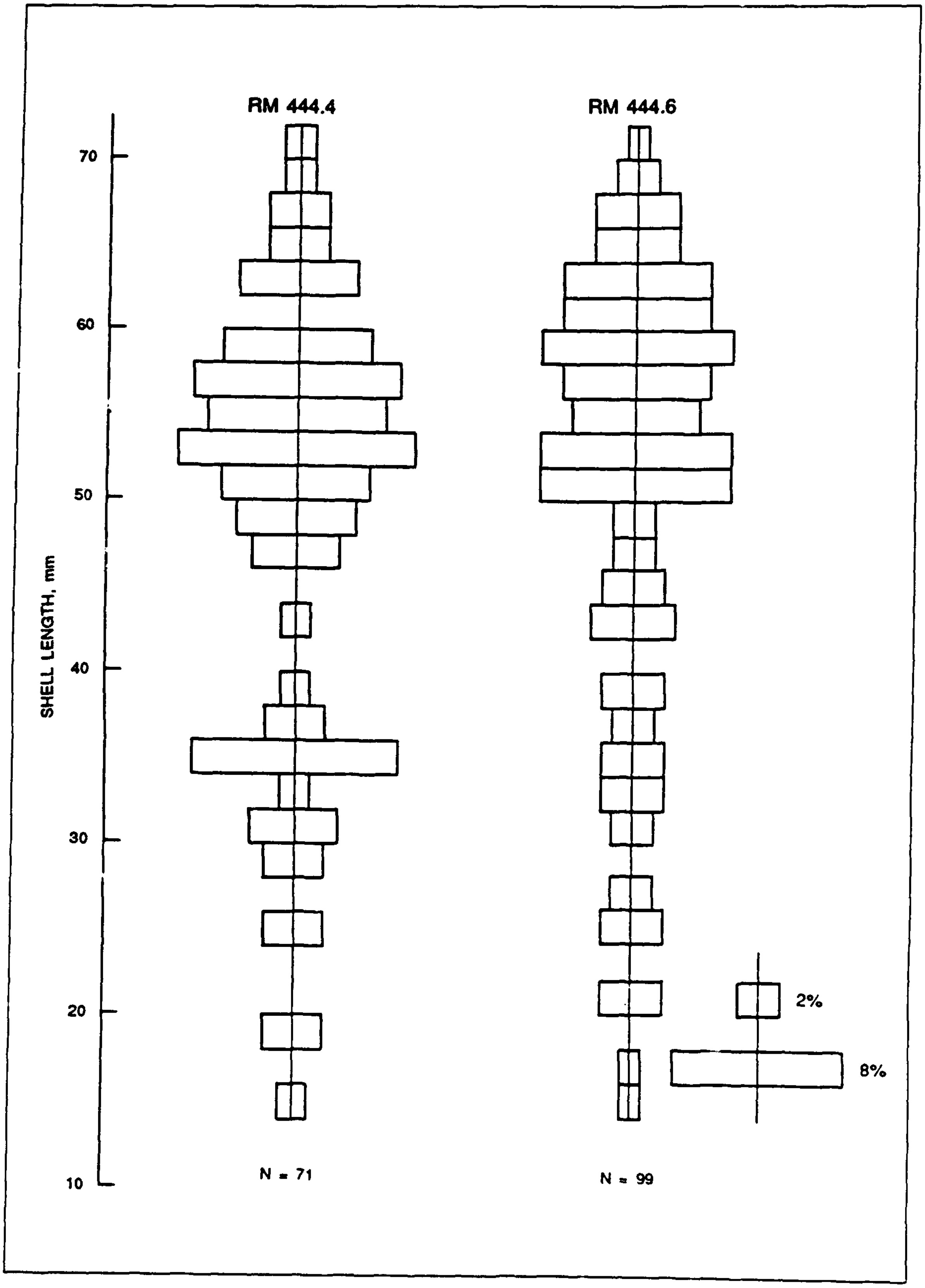


Figure 32. Length-frequency histograms for *Q. pustulosa*, 1989

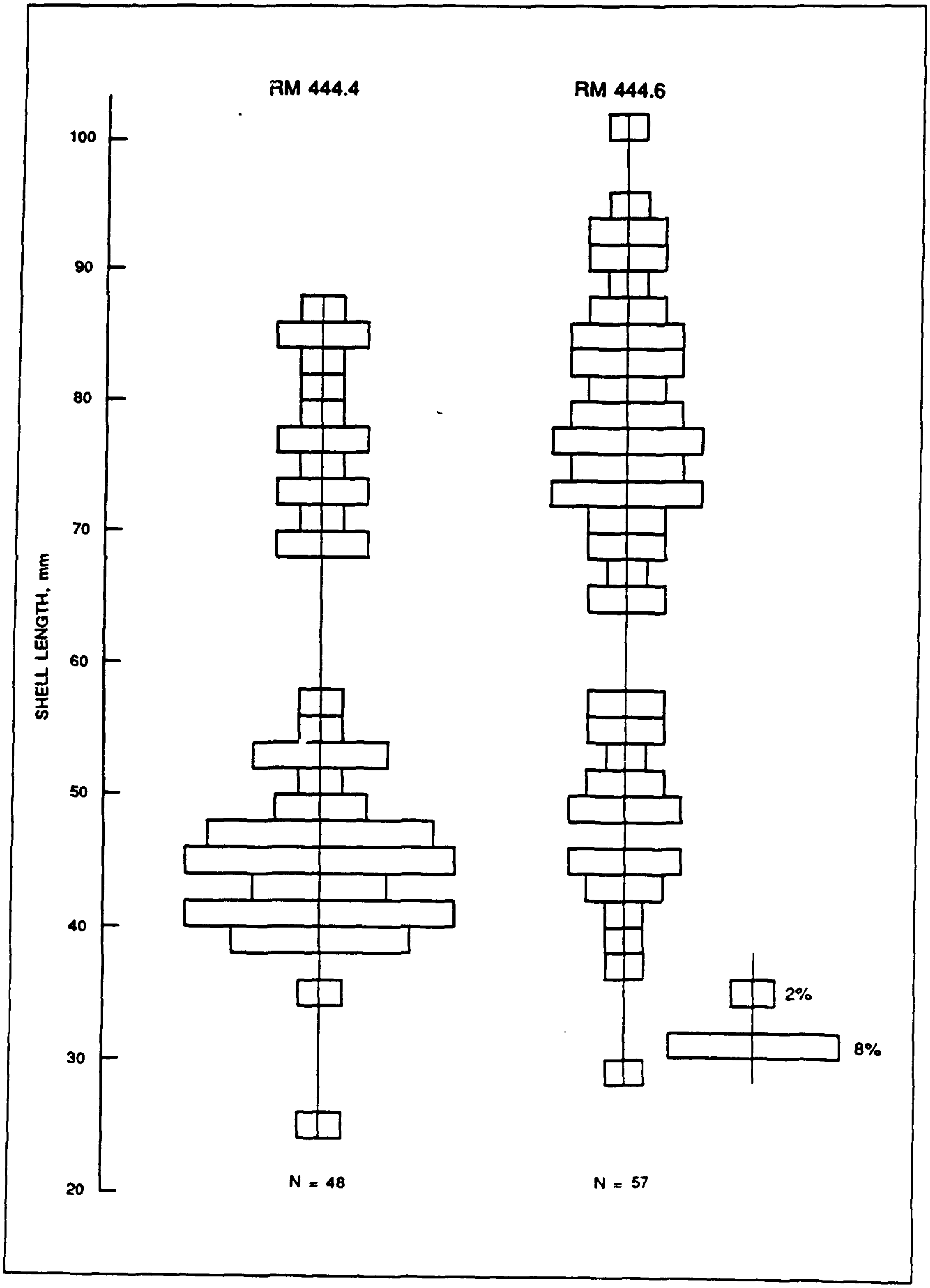


Figure 33. Length-frequency histograms for *P. cordatum*, 1989

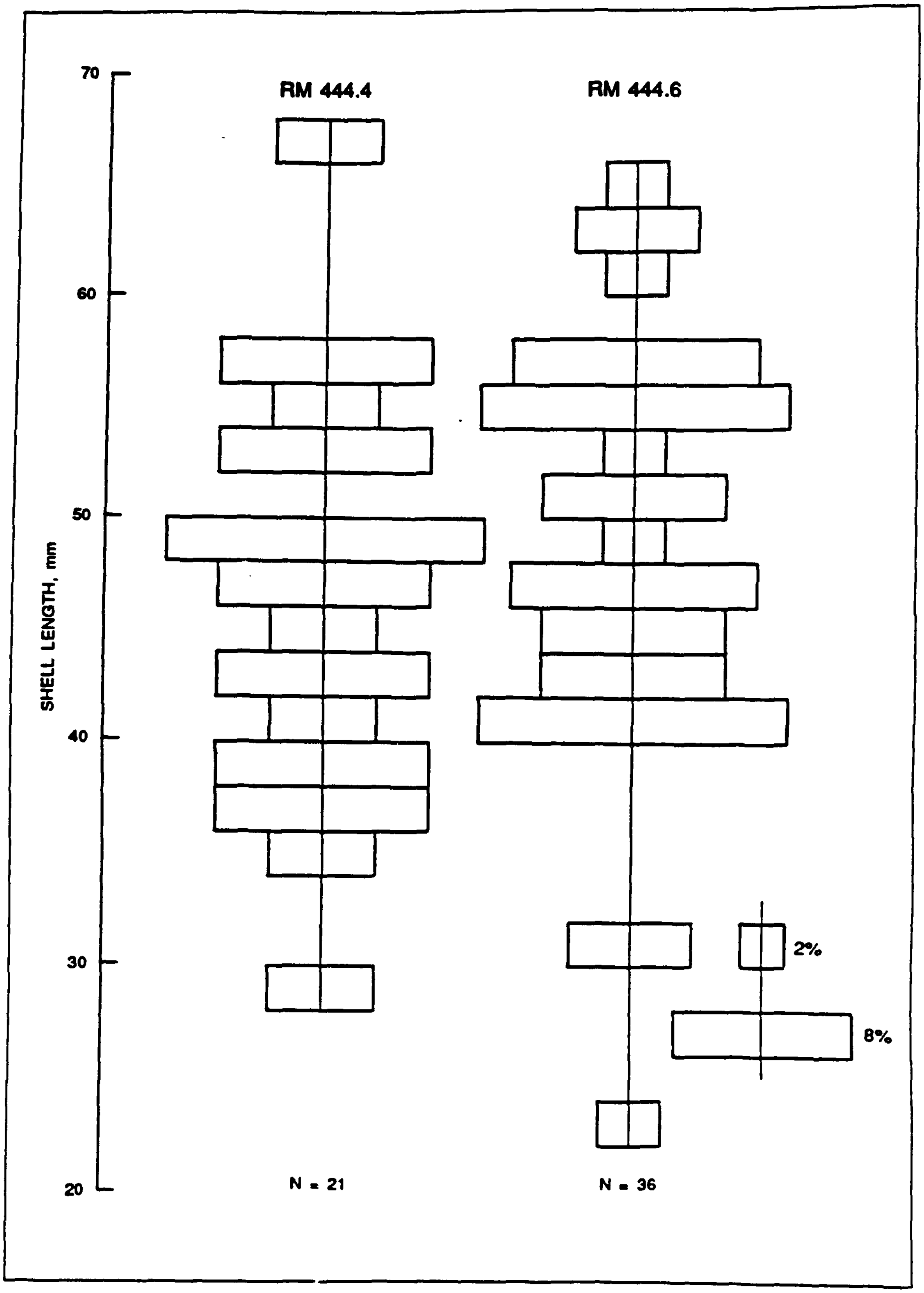


Figure 34. Length-frequency histograms for *O. reflexa*, 1989

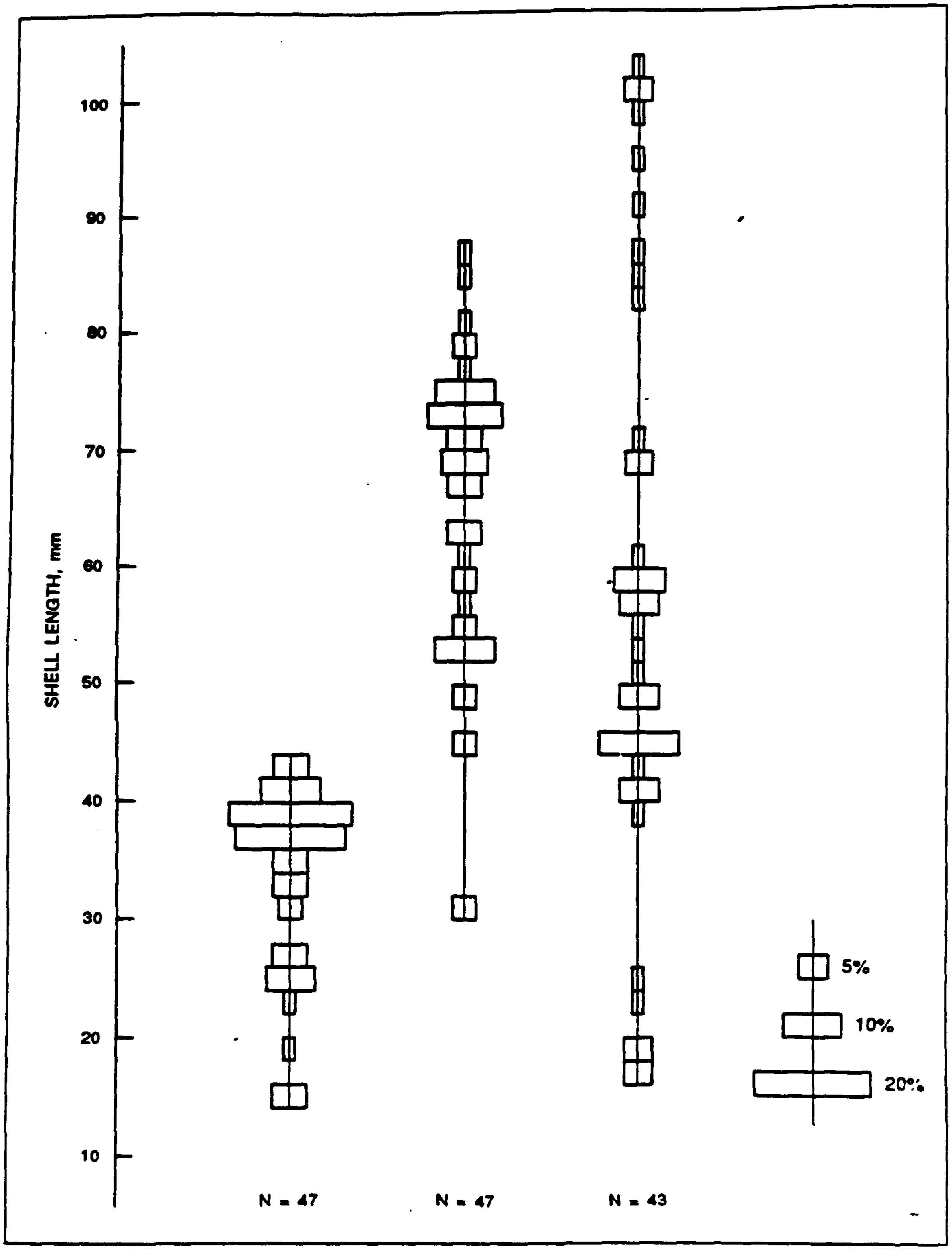


Figure 35. Length-frequency histograms for three species of unionids, 1989. Data from RM 444.4 and RM 444.6 have been combined

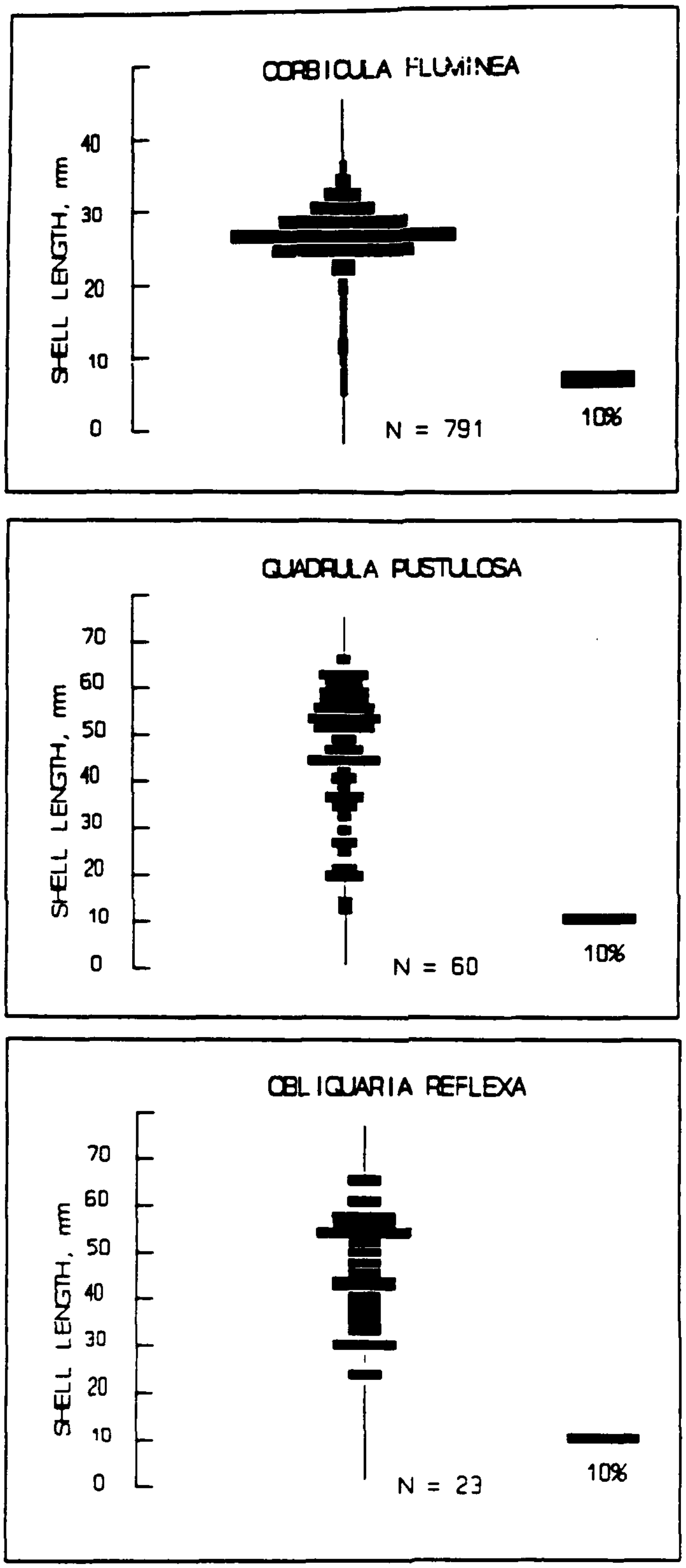
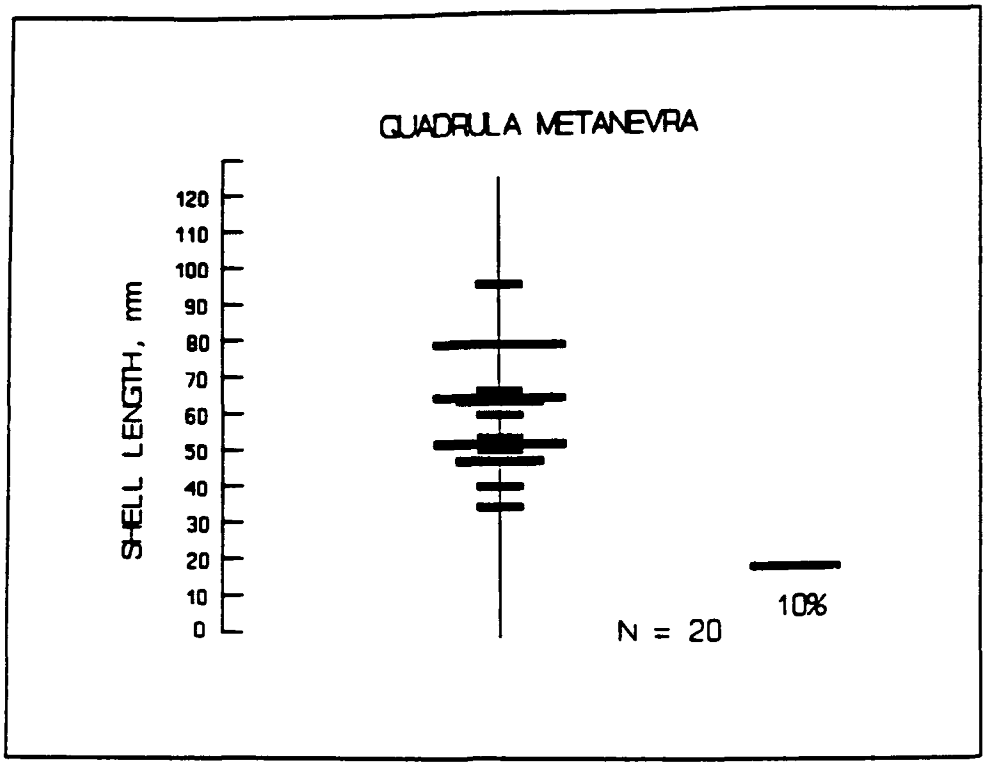


Figure 36. Length-frequency histograms for *C. fluminea*, *Q. pustulosa*, and *O. reflexa* at Ohio River Mile 444.2, 1990



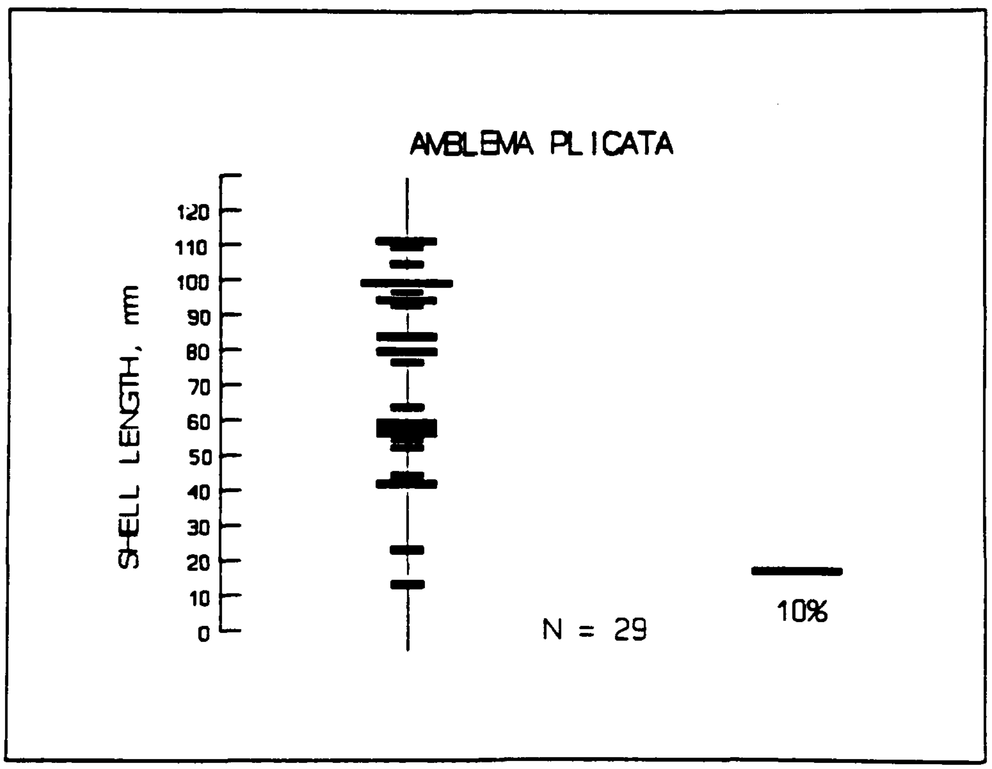


Figure 37. Length-frequency histograms for *Q. metanevra* and *A. plicata* at Ohio River Mile 444.2, 1990

Table 1
Water Depth and Distance to Shore for Study Sites Used in the 1989-90 Mussel Survey at the Zimmer Station, Ohio River[1]

RM	Distance, ft	Depth, ft	No. Samples	No. Mussels	Year
Qualitative Collections					
444.4	220	15	12	168	1989
444.6	240	15	12	206	1989
444.8	220	15	12	215	1989
444.9	200	15	12	204	1989
445.4	200	12	12	205	1989
445.6	200	15	12	187	1989
444.2-a	150	14	12	196	1990
444.2-b	150	12	12	211	1990
444.2-c	100	12	12	206	1990
Quantitative Collections					
444.4	160	15	30	344	1989
444.6	200	15	30	275	1989
444.2-u	140	14	20		1990
444.2-d	160	14	20		1990
Physical Data (Water Chemistry, Suspended Solids, Water Velocity)					
RM	**Distance, ft**	**Depth, ft**	**Velocity, sec**	**Total Solids (No. Samples)**	**Year**
444.4	150	12	540	10	1989
	300	16	608	10	1989
444.4	100	12	—[2]	—	1990

Note: RM 444.2-a - 100 ft below last mooring cell
RM 444.2-b - 330 ft below last mooring cell
RM 444.2-c - 200 ft below last mooring cell
RM 444.2-u - 110 ft downriver of last mooring cell
RM 444.2-d - 300 ft downriver of last mooring cell

[1] Water velocity data recorded at 1-sec intervals (see text for details).
[2] Data for ambient conditions and four events were collected (see Table 3).

Table 2
Summary Statistics for Water Velocity Data Collected at RM 444.4r Adjacent to the Zimmer Station, 23 July 1989[1]

Statistic	Nearshore		Farshore	
	Y	X	Y	X
Mean	0.771	0.199	0.887	0.039
SD	0.106	0.091	0.112	0.093
Min	0.458	-0.050	0.546	-0.316
Max	1.026	0.546	1.174	0.334
Range	0.568	0.596	0.628	0.650
Statistic	**Combined Velocity**	**Flow Direction**	**Combined Velocity**	**Flow Direction**
Mean	0.800	27.285	0.893	7.576
SD	0.112	6.154	0.112	5.908
Min	0.515	8.900	0.547	349.000
Max	0.108	47.700	1.177	26.000
Range	0.565	38.800	0.630	37.000

[1] Data were collected normal to flow (Y) and at 90 deg to flow (facing into the main channel, X) at a nearshore station (150 ft from the bank) and a farshore station (300 ft from the bank). Velocity data were collected for 504 and 608 sec at the nearshore and farshore stations, respectively (see Figures 7 and 8).

Table 3
Background Information on Conditions When Water Velocity Data Were Collected Under Ambient Conditions, and During Vessel Passage Events 1-4 (see Figures 9-13), September 1990

Event No.	River Mile	Bank	Vessel Name	Configuration (L x W)	Total Barges	Vessel Condition	Vessel Distance, ft	Vessel Direction
Ambient	444.4	RDB	(Ambient conditions)	N/A	N/A	N/A	N/A	N/A
1	444.4	RDB	Ashland	5x3	15	Loaded	900	Down
2	444.4	RDB	Orco	5x3	15	Unloaded	800	Up
3	444.4	RDB	WE. H. Dickhoner	2x2	3	Unloaded	600	Down
4	444.4	RDB	No name	5x3	13	Unloaded	1,000	Up

	Real Time					Time from Start of Event, sec						Vessel Speed		
Event	Start	Front of Tow Passes	End of Tow Passes	End of Tug Passes	Stop	Barge Front Passes	Barge End Passes	Tug End Passes	No Barges	Total Length	Total Sec to Pass	ft/sec	mph	Direction
Ambient	114818	N/A	N/A	N/A	115925	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	140111	140526	140644	140657	141035	256	334	347	5	925	78	11.86	8.09	Downriver
2	150907	151216	151349	151402	152133	190	283	296	5	925	93	9.95	6.78	Upriver
3	163850	164022	164056	164107	164457	93	127	138	2	370	34	10.88	7.42	Downriver
4	170537	171056	171410	171448	172321	320	514	522	5	925	194	4.77	3.25	Upriver

Table 4
Summary Statistics for Water Velocity Data Collected at Stations Located 100 ft from the Right Descending Bank of the Ohio River Adjacent to the Zimmer Station, 19 September 1990[1]

Statistic	Y	X	Combined Velocity	Flow Direction
Sensor 946 - Ambient Conditions				
Mean	0.196	0.796	0.820	334.046
SD	0.043	0.081	0.084	2.924
Min	0.097	0.628	0.656	324.900
Max	0.284	0.946	0.977	344.200
Range	0.187	0.318	0.321	19.300
Seconds: 49-250				
Sensor 946 - Event 1				
Mean	0.150	0.537	0.559	332.319
SD	0.049	0.078	0.082	4.529
Min	0.037	0.401	0.436	322.800
Max	0.237	0.712	0.730	342.900
Range	0.200	0.311	0.294	20.100
Seconds: 206-405				
Sensor 946 - Event 2				
Mean	0.142	0.600	0.621	334.734
SD	0.079	0.082	0.080	6.486
Min	-0.020	0.406	0.423	323.300
Max	0.334	0.762	0.826	350.000
Range	0.354	0.356	0.403	26.7
Seconds: 140-339				
Sensor 946 - Event 3				
Mean	0.186	0.852	0.878	336.633
SD	0.114	0.197	0.199	8.006
Min	-0.394	0.419	0.432	325.800
Max	0.371	1.323	1.369	384.900
Range	0.765	0.904	0.937	59.100
Seconds: 43-242				
Sensor 946 - Event 4				
Mean	0.156	0.693	0.713	335.807
SD	0.049	0.070	0.069	4.041
Min	0.040	0.550	0.558	328.200
Max	0.274	0.829	0.860	345.500
Range	0.234	0.279	0.302	17.300
Second: 270-469				

[1] Data were collected normal to flow (X) and at 90 deg to flow (facing into the main channel, Y). The total seconds elapsed, 200, refer to the increment of time for which summary statistics were calculated.

Table 5
Summary Sediment and Water Quality Data Collected at the Zimmer Station, Ohio River, 1989-90

Location	Loss on Ignition (%)	Standard Deviation
Organic Content of Sediments - 1989		
RM 444.4	1.61	0.13
RM 444.6	1.21	0.08
Organic Content of Sediments - 1990		
RM 444.4	1.93	0.15
RM 444.6	1.29	0.11
Parameter	**Surface**	**Bottom**
Water Chemistry-1989 - RM 444.4		
Total hardness (mg/L $CaCO_3$)	132.0	130.0
Total alkalinity (mg/L $CaCO_3$)	80.0	84.0
Total dissolved solids (mg/L)	120.0	124.0
Specific conductance (micromhos)	180.0	180.0
Dissolved oxygen (mg/L)	7.5	7.8
Total sulfate (mg/L)	49.0	52.0
Water temperature (°C)	25.4	24.0
Water Chemistry-1990 - RM 444.4		
Total hardness (mg/L $CaCO_3$)	142.0	138.0
Total alkalinity (mg/L $CaCO_3$)	82.0	86.0
Total dissolved solids (mg/l)	130.0	134.0
Specific conductance (micromhos)	200.0	220.0
Dissolved oxygen (mg/L)	7.9	7.9
Total sulfate (mg/L)	51.0	54.0
Water temperature (°C)	21.4	20.0

Table 6
Relative Abundance (p_i) and Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Qualitative Techniques at the Zimmer Station, Ohio River Mile 444, July 1989 and September 1990[1]

Species	p_i	f_i
Pleurobema cordatum (Rafinesque, 1820)	0.2030	0.8241
Quadrula pustulosa (Lea, 1831)	0.1874	0.8981
Quadrula metanevra (Rafinesque, 1820)	0.1563	0.7407
Amblema plicata (Say, 1817)	0.1001	0.7315
Obliquaria reflexa (Rafinesque, 1820)	0.0745	0.6389
Ellipsaria lineolata (Rafinesque, 1820)	0.0462	0.4444
Megalonaias nervosa (Rafinesque, 1820)	0.0428	0.4167
Elliptio crassidens (Lamarck, 1819)	0.0400	0.3796
Quadrula quadrula (Rafinesque, 1820)	0.0278	0.3056
Fusconaia ebena (Lea, 1831)	0.0234	0.3704
Quadrula nodulata (Rafinesque, 1820)	0.0222	0.2407
Plethobasus cyphyus (Rafinesque, 1820)	0.0150	0.1852
Fusconaia flava (Rafinesque, 1820)	0.0150	0.2130
Cyclonaias tuberculata (Rafinesque, 1820)	0.0089	0.1296
Potamilus alatus (Say, 1817)	0.0083	0.1204
Truncilla truncata (Rafinesque, 1820)	0.0072	0.1019
Tritogonia verrucosa (Rafinesque, 1820)	0.0061	0.1019
Lampsilis ventricosa (Barnes, 1823)	0.0056	0.0926
Actinonaias ligamentina (Lamarck, 1819)	0.0028	0.0463
Leptodea fragilis (Rafinesque, 1820)	0.0022	0.0370
Ligumia recta (Lamarck, 1819)	0.0017	0.0278
Lasmigona costata (Rafinesque, 1820)	0.0011	0.0185
Elliptio dilatata (Rafinesque, 1820)	0.0011	0.0185
Lampsilis abrupta (Say, 1831)	0.0006	0.0093
Anodonta grandis (Say, 1829)	0.0006	0.0093

Total mussels 1,798
Total samples 108

[1] The p_i value equals the number of individuals of species i divided by the total number of individuals collected (1,798). The f_i value equals the number of samples in which at least one individual of that species was collected divided by the total number of samples. A total of 108 samples were obtained (12 at each of 9 sites).

Table 7

Relative Abundance of Freshwater Mussels Collected Using Qualitative Techniques at the Zimmer Station, Ohio River Mile 444, July 1989 and September 1990[1]

Species	River Mile								
	444.4	444.6	445.4	444.8	444.9	445.6	444.2-a[2]	444.2-b[3]	444.2-c[4]
P. cordatum	0.1071	0.0777	0.2244	0.2512	0.2647	0.3209	0.2602	0.2085	0.1068
Q. pustulosa	0.1131	0.1214	0.1415	0.2372	0.1863	0.1283	0.2551	0.2654	0.2184
Q. metanevra	0.3333	0.2913	0.0537	0.1814	0.1863	0.0749	0.0765	0.0758	0.1553
A. plicata	0.1310	0.1311	0.1122	0.0372	0.0588	0.0642	0.0918	0.1185	0.1602
O. reflexa	0.0774	0.1602	0.0390	0.0465	0.0833	0.0428	0.0561	0.0711	0.0922
E. lineolata	0.0119	0.0097	0.0390	0.0465	0.0686	0.0695	0.0663	0.0616	0.0388
M. nervosa	0.0119	0.0000	0.1707	0.0093	0.0294	0.0267	0.0408	0.0569	0.0340
E. crassidens	0.0238	0.0049	0.0829	0.0326	0.0392	0.1283	0.0255	0.0142	0.0146
Q. quadrula	0.0536	0.0000	0.0439	0.0372	0.0098	0.0321	0.0255	0.0190	0.0340
F. ebena	0.0357	0.0243	0.0146	0.0186	0.0098	0.0107	0.0255	0.0142	0.0583
Q. nodulata	0.0476	0.0534	0.0098	0.0186	0.0196	0.0214	0.0153	0.0190	0.0000
P. cyphyus	0.0238	0.0437	0.0000	0.0093	0.0049	0.0107	0.0204	0.0237	0.0000
F. flava	0.0000	0.0000	0.0195	0.0093	0.0196	0.0053	0.0153	0.0332	0.0291
C. tuberculata	0.0000	0.0000	0.0049	0.0279	0.0049	0.0374	0.0000	0.0047	0.0000
P. alatus	0.0000	0.0243	0.0146	0.0093	0.0000	0.0000	0.0000	0.0095	0.0146
T. truncata	0.0060	0.0146	0.0098	0.0186	0.0049	0.0000	0.0000	0.0000	0.0097

[1] Species diversity = Log$_{(2.3026)}$.
[2] Site 160 ft downriver of mooring cell.
[3] Site 330 ft downriver of mooring cell.
[4] Site 200 ft downriver of mooring cell.

Continued

Table 7 (Concluded)

Species	River Mile								
	444.4	444.6	445.4	444.8	444.9	445.6	444.2-a	444.2-b	444.2-c
T. verrucosa	0.0060	0.0049	0.0146	0.0000	0.0049	0.0160	0.0000	0.0000	0.0097
L. ventricosa	0.0119	0.0194	0.0000	0.0000	0.0000	0.0000	0.0000	0.0047	0.0146
A. ligamentina	0.0000	0.0097	0.0000	0.0047	0.0000	0.0000	0.0051	0.0000	0.0049
L. fragilis	0.0000	0.0097	0.0049	0.0000	0.0049	0.0000	0.0000	0.0000	0.0000
L. recta	0.0000	0.0000	0.0000	0.0000	0.0000	0.0053	0.0102	0.0000	0.0000
L. costata	0.0000	0.0000	0.0000	0.0000	0.0000	0.0053	0.0051	0.0000	0.0000
E. dilatata	0.0000	0.0000	0.0000	0.0047	0.0000	0.0000	0.0000	0.0000	0.0049
L. abrupta	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
A. grandis	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0051	0.0000	0.0000
Total mussels	168	206	205	215	204	187	196	211	206
Total species	16	16	17	18	17	17	17	16	17
Species diversity	2.164	2.171	2.316	2.185	2.141	2.240	2.201	2.217	2.323
Evenness	0.781	0.783	0.818	0.756	0.756	0.791	0.777	0.800	0.820
Simpson dominance	0.162	0.152	0.124	0.159	0.154	0.152	0.155	0.145	0.123

Table 8
Summary Statistics for Unionids Collected in 0.25-m^2 Quadrats at the Zimmer Station, Ohio River Mile 444, 21-23 July 1989

RM	Subsite	Species	Unionids Average Density	Unionids Standard Deviation	*Corbicula* Average Density	*Corbicula* Standard Deviation
444.2-u	1	6	4.4^{d}	6.8	66.8^{g}	67.7
	2	18	35.2^{bc}	25.8	161.6^{g}	81.5
Total		**18**	**19.8**	**24.2**	**114.2**	**87.6**
444.2-d	1	18	31.2^{bc}	9.8	613.2^{f}	92.4
	2	14	22.0^{c}	4.3	857.6^{de}	88.7
Total		**20**	**26.6**	**8.7**	**735.4**	**153.3**
444.4	1	6	30.0^{bc}	15.2	$1,092.4^{bc}$	358.4
	2	14	39.6^{ba}	28.1	$1,238.0^{ba}$	258.3
	3	17	40.4^{ba}	15.8	$1,352.8^{a}$	96.1
Total		**20**	**36.7**	**20.4**	**1,227.7**	**274.2**
444.6	1	20	46.4^{ba}	17.1	$1,009.2^{dc}$	110.3
	2	16	52.4^{a}	13.9	939.6^{dce}	141.1
	3	16	38.8^{ba}	10.7	796.8^{e}	140.6
Total		**21**	**45.9**	**14.8**	**915.2**	**155.5**

	Unionids F	Unionids p	*C. fluminea* F	*C. fluminea* p
Comparison among subsites	6.7	0.0001	63.7	0.0001

Note: Means with the same superscript letter are not significantly different ($p > 0.05$).

Table 9
Relative Abundance (p_i) and Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Quantitative Techniques at the Zimmer Station, Ohio River Mile 444, 21-23 July 1989[1]

Species	RM 444.4		RM 444.6	
	p_i	f_i	p_i	f_i
Q. pustulosa	0.2878	1.0000	0.2582	0.6667
P. cordatum	0.1657	0.9333	0.1745	0.6667
O. reflexa	0.1047	0.7000	0.0764	0.5000
Q. metanevra	0.0814	0.5667	0.0691	0.4667
T. truncata	0.0669	0.4667	0.0873	0.6000
A. plicata	0.0640	0.5667	0.0764	0.4000
E. lineolata	0.0494	0.4333	0.0691	0.4667
E. crassidens	0.0407	0.3333	0.0218	0.2000
Q. quadrula	0.0291	0.3000	0.0182	0.1667
C. tuberculata	0.0174	0.1667	0.0073	0.0667
F. flava	0.0145	0.1333	0.0255	0.2000
T. donaciformis	0.0145	0.1333	0.0145	0.1333
A. ligamentina	0.0116	0.1000	0.0145	0.1000
F. ebena	0.0116	0.1333	0.0073	0.0667

[1] The p_i value equals the number of individuals of species i divided by the total number of individuals collected; f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples. At each of the two sites, thirty 0.25-m^2-quadrat samples were collected.

Continued

Table 9 (Concluded)

Species	RM 444.4		RM 444.6	
	p_i	f_i	p_i	f_i
M. nervosa	0.0116	0.1000	0.0073	0.0667
Q. nodulata	0.0116	0.1000	0.0255	0.2333
P. alatus	0.0058	0.0667	0.0073	0.0667
L. recta	0.0029	0.0333	0.0073	0.0667
L. ventricosa	0.0029	0.0333	—	—
P. cyphyus	0.0029	0.0333	0.0036	0.0333
T. verrucosa	0.0029	0.0333	—	—
L. fragilis	—	—	0.0291	0.2667
Total species	21		20	
Total individuals	344		275	
Total quadrats	30		30	
Diversity (H')[1]	2.33		2.40 (t = 0.0065, ns)[2]	
Evenness	0.76		0.80	
No. of individuals less than 30 mm SL	37 (10.8%)		33 (12.0%)	
No. of species with individuals less than 30 mm SL	11 (52.4%)		10 (50.0%)	

[1] Species diversity = $Log_{(2.3026)}$.
[2] Not significant ($p > 0.05$).

Table 10
Relative Abundance (p_i) and Frequency of Occurrence (f_i) of Freshwater Mussels Collected Using Quantitative Techniques at the Zimmer Station, Ohio River Mile 444, September 1990[1]

Species	RM 444.2-u		RM 444.2-d	
	p_i	f_i	p_i	f_i
Q. pustulosa	0.2323	0.5500	0.2357	0.9000
A. plicata	0.1414	0.4000	0.0955	0.4500
O. reflexa	0.0505	0.2000	0.1146	0.7000
F. flava	0.0606	0.3000	0.0955	0.4500
Q. metanevra	0.1010	0.2500	0.0637	0.3500
T. truncata	0.0808	0.3500	0.0573	0.4500
E. lineolata	0.0505	0.2000	0.0701	0.5500
P. cordatum	0.0202	0.1000	0.0764	0.5000
F. ebena	0.0707	0.1000	0.0382	0.3000
C. nodulata	0.0404	0.1500	0.0318	0.2500
E. crassidens	0.0303	0.1500	0.0255	—
M. nervosa	0.0101	0.2000	0.0382	0.3000
Q. quadrula	0.0404	0.1500	0.0064	0.0500
P. cyphyus	0.0202	0.1000	0.0127	0.1000

[1] The p_i value equals the number of individuals of species i divided by the total number of individuals collected; f_i equals the number of samples in which at least one individual of that species was collected divided by the total number of samples. At each of the two sites, twenty 0.25-m^2-quadrat samples were collected.

Continued

Table 10 (Concluded)

Species	RM 444.2-u		RM 444.2-d	
	p_i	f_i	p_i	f_i
C. tuberculata	0.0202	0.1000	—	—
A. ligamentina	0.0101	0.0500	0.0064	0.0500
T. verrucosa	0.0101	0.0500	0.0064	0.0050
P. alatus	0.0101	0.2500	—	—
L. recta	—	—	0.0064	0.0500
L. fragilis	—	—	0.0064	0.0500
L. costata	—	—	0.0064	0.0500
P. sintoxia	—	—	0.0064	0.0050
Total species	18		20	
Total individuals	99		157	
Total quadrats	20		20	
Diversity (H')[1]	2.496		2.491	
Evenness	0.864		0.832	
No. of individuals less than 30 mm SL	9 (9.09%)		17 (10.8%)	
No. of species with individuals less than 30 mm SL	4 (22.2%)		3 (10.3%)	

[1] Species diversity = $Log_{(2.3026)}$.

Table 11
Mean Biomass and Standard Deviation per Square Meter for Unionids and *Corbicula fluminea* Collected in 0.25 m² Quadrats at the Zimmer Station, Ohio River Mile 444, 21-23 July 1989

RM	Subsite	Unionids Mean	Unionids SD	*Corbicula* Mean	*Corbicula* SD
444.2-u	1	430.7^{d}	705.1	499.9^{e}	506.8
	2	4,148.6^{ab}	2,822.1	1,263.6^{d}	543.4
Total		2,289.6	2,765.0	881.8	644.2
444.2-d	1	3,785.6^{ab}	2,058.4	4,258.5^{b}	650.7
	2	2,148.2^{bdc}	1,103.5	6,048.8^{a}	606.9
Total		2,967.0	1,813.7	5,162.6	1,097.7
444.4	1	1,584.6^{dc}	1,064.8	4,401.7^{b}	1,491.9
	2	3,390.2^{abc}	3,041.0	5,637.8^{a}	1,007.1
	3	2,293.9^{bdc}	947.2	5,691.6^{a}	482.4
Total		2,422.9	2,017.7	5,243.7	1,174.7
444.6	1	3,998.8^{ab}	1,804.4	3,989.8^{b}	442.2
	2	5,471.6^{a}	3,521.1	3,771.2^{b}	522.6
	3	3,774.1^{ab}	1,920.2	2,910.3^{c}	522.2
Total		4,414.8	2,566.8	3,557.1	674.3

	Unionids F	Unionids p	*C. fluminea* F	*C. fluminea* p
Comparison among subsites	4.87	0.0001	63.7	0.0001

Note: Means with the same superscript letter are not significantly different ($p > 0.05$).